

# Landslide Identification and Information Extraction Based on Optical and Multispectral UAV Remote Sensing Imagery

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**Abstract.** Landslide is one of the most serious natural disasters which caused enormous economic losses and casualties in the world. Fast and accurate identification of newly occurred landslide and extraction of relevant information are the premise and foundation for landslide disaster assessment and relief. As the places where landslides occur are often inaccessible for field observation because of the temporary failure in transportation and communication. Therefore, UAV remote sensing can be adopted to collect landslide information efficiently and quickly with the advantages of low cost, flexible launch and landing, safety, under-cloud-flying, and hyperspatial image resolution. Newly occurred landslides are usually accompanied with those phenomena such as vegetation burying and bedrock or bare soil exposure, which can be easily detected in optical or multispectral UAV images. By taking one typical landslide occurred in Wenchuan Earthquake stricken area in 2010 as an example, this paper demonstrates the process of integration of multispectral camera with UAV platform, NDVI generation with multispectral UAV images, three-dimensional terrain and orthophoto generation with optical UAV images, and identification and extraction of landslide information such as its location, impacted area, and earthwork volume.

## 1. Introduction

Landslide refers to the slope deformation phenomena caused by natural forces such as the gravity applied to slope-composed materials (Delacourt, C., et al., 2007). It is one of the most serious natural disasters, which causes enormous economic losses and casualties only second to earthquake (Derek C., 2005). The plateau and mountainous region are widely distributed in Southwest China, therefore landslides occur very frequently due to the complex geological environment and harsh weather conditions. After the earthquakes in Wenchuan, Lushan, and Ludian, the rock and soil in the near surface of the disastrous area is so loose that the risk of landslide occurrence is very high when induced by strong rainfall and surface runoff (Yin Yueping, 2009). So we need to timely carry out



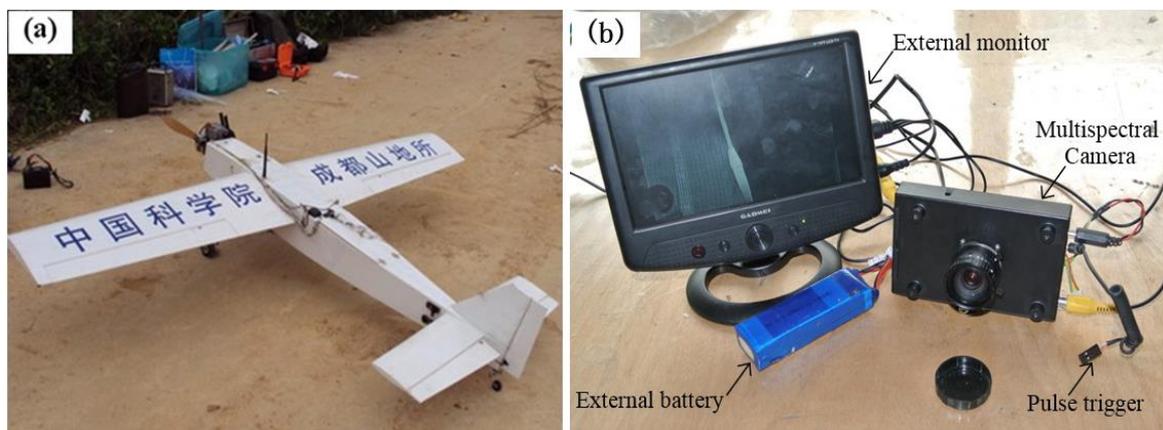
landslide investigation, identification and extraction of information about their locations, impacted areas and earthwork volumes, and assessment of landslide hazard in the earthquake stricken areas.

With the advantages of low cost, flexible launch and landing, safety, under-cloud-flying, hyperspatial image resolution, Unmanned Aerial Vehicles (UAVs) are very suitable for obtaining remote sensing imagery to investigate newly occurred landslides (Lin, J., 2010). Newly-occurred landslides are usually accompanied by the phenomena of lodged or covered vegetation and exposed bedrock or bare soil (Zhang, W., et al., 2010). Therefore, we can employ obvious difference between the vegetation and the surrounding environment to identify newly occurred landslides using NDVI (Normalized Difference Vegetation Index) images of the before and after landslide occurrence in the target area. The accuracy of landslide identification will be improved with the consideration of terrain conditions. The NDVI images will be generated based on the multispectral remote sensing images acquired by multispectral camera mounted on the UAV. Then information about identified newly occurred landslides such as impacted area and earthwork volume can be extracted from the optical images or the corresponding pseudo colour images.

## 2. UAV system and raw data

### 2.1. Integration of multispectral camera with UAV platform

The UAV remote sensing system employed to investigate landslides is composed of four major components: fixed-wing UAV platform (Figure 1.a), ground station control system, flight control system, and remote sensor (optical or multispectral camera, Figure 1.b). Due to the UAV's limited payload, the on-board remote sensors are restricted in their weight and size. The ADC (Agricultural Multispectral Camera) used in our study has the size of 114 mm x 77 mm x 22 mm, the weight of 200 g, and three bands (red, green, near infrared) (Tetracam Inc., 2011). The vegetation indexes including NDVI (Normalized Difference Vegetation Index), SAVI (Soil Adjusted Vegetation Index), etc. can be obtained after processing raw images using the accompanied software.



**Figure 1.** Fixed-wing UAV and multispectral camera.

The multispectral camera has certain differences in performance parameters and usage from the household SLR visible light camera usually used on UAV. Therefore, it is necessary to transform its hardware interfaces to be integrated with UAV remote sensing platform. In addition, multispectral camera could only be adjusted to the best working status after many field operations amounted on UAV. The specific measures and configurations (as shown in Figure 1.b) mainly include:

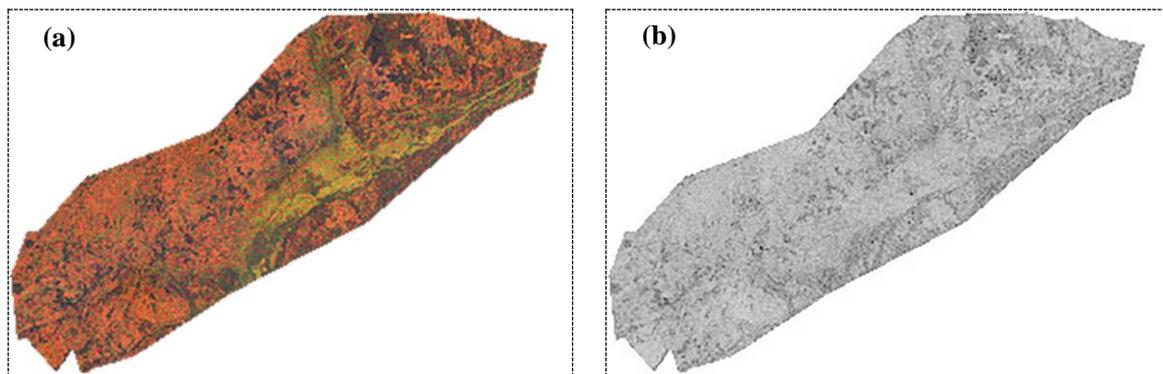
- Multispectral camera lens focal length and aperture adjustment. In the use of household SLR cameras on UAV, the lens focal length is usually set to infinity. However, the lens focal length of the multispectral camera should be adjusted according to the flight height of the UAV to get clear images. Its lens aperture size should be adjusted according to the environment light, which is

usually completed through the external connected LED monitor after many test shots. We should choose the situation of the image looking slightly darker as the appropriate aperture setting. At the same time, the white board image should also be captured simultaneously in order to carry out radiation correction.

- Multispectral image storage format and exposure time setting. Since the multispectral camera continuously takes photographs during the UAV flight process, the time interval is relatively short, usually 3 seconds or so, and the time taken to store photographs into the memory card should also be counted in. Therefore, the storage format should be set as RAW8 (storage time of less than 1 second) and the exposure time set as 1 second in order to shorten the time of photograph taking and storage. If not set so, the unsynchronization and unmatched number between the recorded flight attitude data and photographs will possibly happen and as a result later aerotriangulation cannot be done correctly.
- Configuration of external power supply and pulse trigger device. As two batteries sold on the market can only maintain one hour continuous shooting of the multispectral camera, external power supply must be employed, which can support five-hour continuous shooting and satisfy the needs of the most UAV tasks. At the same time, the multispectral camera cannot be manually pressed to take pictures when amounted on UAV, therefore, it is necessary to configure pulse trigger device, so that pulse signals can be sent to the multispectral camera by the flight control system and complete the picture taking tasks.

## 2.2. NDVI generation with multispectral UAV image

The multispectral camera captures three channels grey image (Green, Red and NIR, which approximately equal to TM2, TM3 and TM4 of Landsat 7). We can use the accompanied PixelWrench2 software to obtain pseudo colour image (Figure 2.a) and vegetation index image, such as NDVI (Normalized Difference Vegetation Index) (Figure 2.b). As we know, green vegetation rich in chlorophyll has a strong reflection in the near infrared band. As Figure 2.a displays, near infrared channel replaced the red channel and vegetation in the figure are usually red colour. This is known as pseudo colour image, which is much convenient for technicians to do visual interpretation.



**Figure 2.** Multispectral pseudo colour image and corresponding NDVI image.

NDVI is most popular vegetation index. Its formula is shown below:

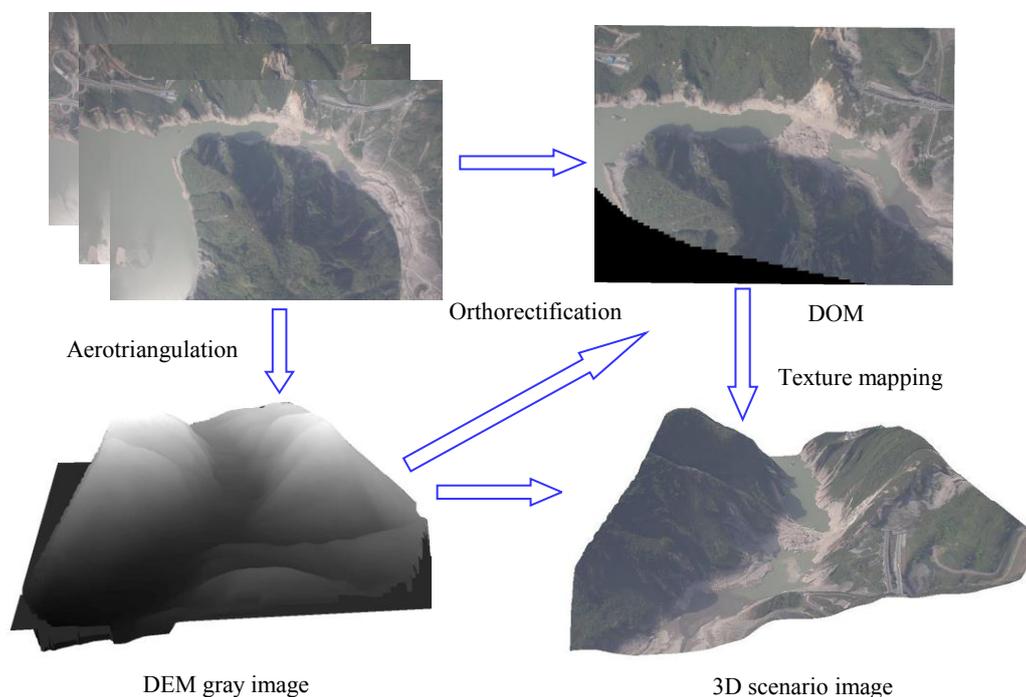
$$NDVI = (\rho_{nir} - \rho_r) / (\rho_{nir} + \rho_r) \quad (1)$$

Based on the above formula, the NDVI vegetation index image (Figure 2.b) can be acquired. It is a grey scale image, which is different from false colour image. The higher the NDVI index, the greater the value of the image displayed, and the denser and lusher the corresponding vegetation (Pettorelli, N., et al., 2005).

After producing the false-colour images and NDVI grey images, the panoramic orthorectified UAV image of target area can be acquired using aerial triangulation software with combination of the image spatial coordination (X, Y, Z) and attitude data (heading angle, roll angle, pitch angle). In the processing procedures the corresponding panoramic DSM (Digital Surface Model) is also produced.

### 2.3.2. Optical UAV image

The optical UAV images of the same area were taken in different time from those multispectral images. Compared with multispectral images, the optical images have higher spatial resolution and more textural information. Due to 60% to 80% overlap between acquired images, the good quality DEM and DOM of target area can be produced with the interior orientation parameters from digital camera calibration and the exterior orientation parameters namely the attitude data recorded in UAV flight. Here we will demonstrate the aerotriangulation in details.



**Figure 3.** Generation of DOM and DEM data with optical UAV images.

- 3D terrain generation. Exterior orientation parameters recorded during UAV flight include photo reference number, latitude, longitude, relative height, roll angle, pitch angle, heading angle, and altitude above sea level. We use the modern Switzerland aerial triangulation software Pixel4UAV to generate 3D terrain data of target disaster area. Specific steps include putting UAV images and corresponding exterior and interior orientation data into the aerotriangulation software, automatically searching for matching tie points between adjacent images, and conducting aerial triangulation analytical operations to generate 3D terrain data, namely DEM (Digital Elevation Model) of target disaster area (see Figure.3).
- Image orthorectification and mosaicking. An orthophotograph is an aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map (Lear, A.C., 1997). Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt. The generated DEM will be used to orthorectify the corresponding UAV image to generate

orthorectified image, namely DOM (Digital Orthophoto Map). As shown in Figure. 3, the DOM of the whole target area was obtained by mosaicking all DOM blocks in the UTM WGS84 coordinate system.

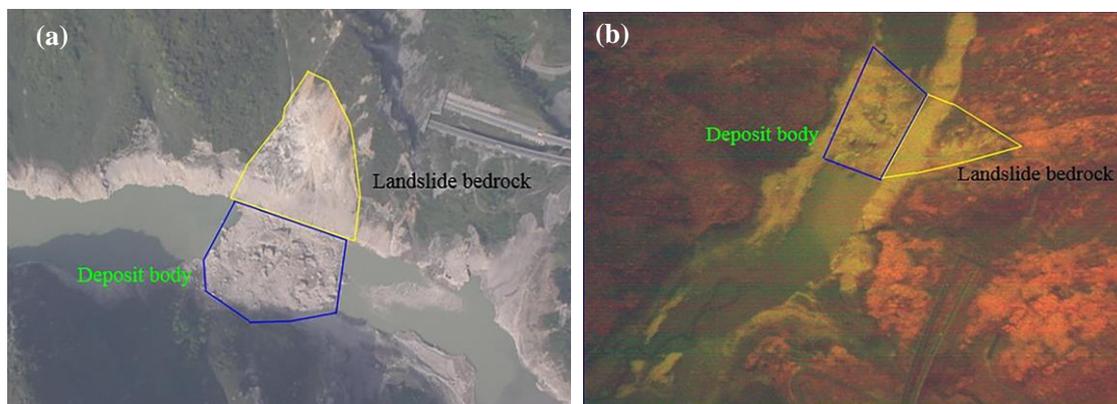
- Texture mapping. We can use 3D display software such as ArcScene to map the DOM of target landslide area to the DEM of the same area (see Figure. 3). Since both the DEM terrain data and DOM data are from the UAV remote sensing images, they fit each other perfectly with excellent visual effects and make the interpretation and identification of landslides more accurately and intuitively.

### 3. Landslide Identification and information extraction

#### 3.1. Identification of landslide slope surface and deposit body

Since newly occurred landslides are usually accompanied by the phenomena such as falling and buried vegetation, exposed bare soil or base rock, we can utilize UAV optical images, pseudo colour images, and NDVI images generated from UAV multispectral images to identify newly occurred landslides by analysing strong differences between the landslide surface vegetation and the surrounding environment with consideration of local terrain conditions.

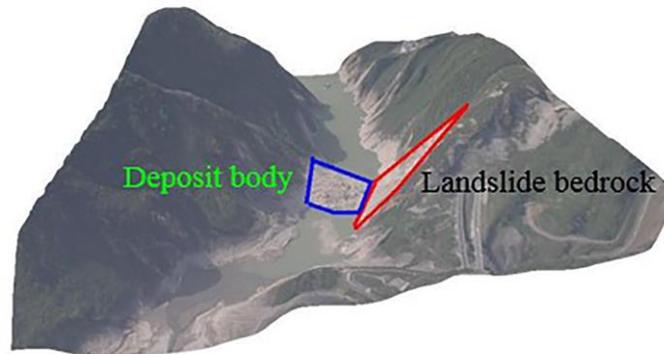
As shown in Figure 4, the landslide slope surface (yellow line surrounded region) and deposit body (blue line surrounded region) are sketched out on both optical image and pseudo colour image respectively. The optical image and false colour image are captured in different angle and different time. The former was captured in 2011, and the latter in 2013. Based on visual interpretation, it can be seen from the Figure 4.b that the spatial extent of the landslide slope surface has been significantly reduced after two years, and the peripheral area of the landslide slope surface and even part of the intermediate region has grown some plants.



**Figure 4.** Identification and distinguishment of landslide bedrock surface and deposit body on optical image (captured in 2011) and pseudo color image (captured in 2013).

#### 3.2. Distinguishment between landslide slope bedrock and deposit body

As shown in Figure 4, directly acquired UAV images are two-dimensional, so it is very easy to take landslide slope surface and deposit body as a whole if just taking bare soil or rock situation into account. To distinguish landslide slope surface from its deposit body, one indirect method is to consider the natural surroundings, where the landslide deposit body is located in the river. Another more direct method is to use the 3D scenario image (DOM mapped on DEM) of the landslide area generated by UAV images. The landslide slope surface is generally steep, and the deposit body is relatively flat. As shown in Figure 5, in the three-dimensional virtual environment, the distinguishment between landslide slope surface and deposit body are very intuitive.



**Figure 5.** Distinguishment landslide bedrock surface from deposit body in 3D scenario.

### 3.3. Landslide impacted area measurement

As both the DOM and DEM are georeferenced, the landslide impacted area can be directly measured using the measurement tools in 3D scenario display software such as ARCSce (Kennedy, K. H., 2009). The landslide slope surface area measured from the optical image in 2011 is about 25, 000 square meters, and the deposit body area is about 31, 600 square meters. However, the landslide slope surface area measured from the pseudo colour image in 2013 is about 16, 000 square meters, and the deposit body area is about 30, 000 square meters. It can be noticed that the spatial extent of the landslide slope surface has been significantly reduced after two years, but that of the landslide deposit body has relatively slight deceased. The reason for the slope surface area change may be the vegetation growth. The peripheral area of the landslide slope surface has gradually grown some plants, but nearly none plants has grown on the deposit body. As for the deposit body area change may be the different water level in two years.

**Table 1.** Landslide slope surface and deposit body area in 2011 and 2013.

Year	Image type	Slope surface area square meters	Deposit body area square meters
2011	RGB	25, 000	31, 600
2013	Multispectral	16, 000	30, 000
	Area Change	9,000	1,600

### 3.4. Landslide earthwork volume estimation

Terrain analysis can be done on the 3D terrain data, including contour generation, slope orientation, slope, and so on. In theory, the landslide earthwork volume can also be measured in 3D scenario. However, the measurement of landslide earthwork volume is different from landslide impacted area measurement. The landslide earthwork volume can be calculated by reducing the current 3D terrain from the 3D terrain that generated before the landslide occurred. It is a pity that we do not have the 3D terrain before landslide occurred. Therefore, we cannot take this high precision method to calculate the landslide earthwork volume. One alternative method, as the formula (2) shows, is to multiply the deposit body area measured from optical image with estimated deposit body height which is about 5 meters (average local river depth plus the average height of deposit body exposed above water surface). As a result, the estimated landslide earthwork volume is about 158,000 cubic meters (31,600 square meters\*5 meter).

$$V_{Le} \approx A_d * (H_e + D_r) \quad (2)$$

Where  $V_{Le}$  is the target landslide earthwork volume;  $A_d$  is the landslide deposit body area;  $H_e$  is the height of the deposit body exposed above the river water surface;  $D_r$  is the average local river depth.

#### 4. Conclusion

Landslide refers to the slope deformation phenomena caused by natural forces such as the gravity applied to slope-composed materials. It is one of the serious natural disasters, which causes enormous economic losses and casualties only second to earthquake. Newly occurred landslides are usually accompanied with those phenomena including vegetation burying and bedrock or bare soil exposure. Therefore, they can be easily identified in optical or multispectral UAV images by detecting sharp vegetation change combined with local steep terrain. In our study, we take one typical landslide occurred in Wenchuan Earthquake stricken area in 2010 as an example. We demonstrate the process of integration of multispectral camera with UAV platform, NDVI generation with multispectral UAV images, orthophoto and three-dimensional terrain generation with optical UAV images, and identification and extraction of landslide information such as its the location, impacted area, and earthwork volume. The different area changes of landslide slope surface and deposit body from 2011 to 2013 and the possible reasons are discussed. We took advantage of the landslide deposit body to estimate the landslide earthwork volume without the 3D terrain acquired before the landslide occurred. Results prove the feasibility and effectiveness of applying the fixed wing UAV system to rapid identification and information extraction of newly occurred landslides under harsh natural conditions including complex terrain and deficient background materials.

#### Acknowledgements

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