Multi-resolution remote sensing data in landslide activity inventory mapping

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Abstract. This paper reviews an application of multi-resolution remote sensing data in landslide activity inventory mapping. Landslide activity is an important component for landslide study. On that basis, remote sensing technology become a standard method in getting and deriving the information related to landslide events. The capability of remote sensing technology in acquiring the geospatial data have accelerate the process of landslide activity inventory mapping. A general overview of several remote sensing techniques applied to landslides is given, followed by a review of landslide characteristics and landslide activity inventory mapping. This paper also emphasizes on the role of vegetation anomalies as bio-indicator for landslide activity inventory mapping. Five (5) indicators have been listed together with the findings from previous research. This kind of approach has opening a new perspective of landslide activity inventory mapping which integrating with multi-resolution remote sensing data that significantly increase the effectiveness of any landslide studies.

1. Introduction
Landslide events have significantly give an adverse impact to the world [1]. These including effects on civilians, properties, environment, and infrastructures [2][3]. Landslide can be characterized as the mass movement process on the natural and artificial slopes [4]. In the last decades, impact of climate change and increasing of urban areas or deforestation have led to an increase of landslide occurrences [5][6]. The slope-forming materials including rock soil may shift by falling, toppling, sliding, spreading, or flowing [1]. Region with steep slope are more likely to experience landslide especially when triggered by tectonic activities and presence of active faults [7]. Many studies have been made in investigating the landslide phenomenon. Advancement of remote sensing technology has opening up new perspective of landslide investigation with the capability of acquiring 3D information of the Earth’s surface [5] and may speed up the process of landslide inventory maps production [8]. Landslide investigation have through both of approaches i.e. qualitative and quantitative [7][9], and were discussed in many research papers [10]. The chosen method relies upon the extent of study area, knowledge, handy experience, monetary expenses and time limitations. [11]. Qualitative approaches depend on expert evaluation which carrying out the analysis [12] while quantitative approaches generate numerical assessments of the landslide occurrences in any hazard zone. Nowadays, the effectiveness of landslide studies increased rapidly due to the advancement of Earth Observation (EO).
techniques. Remote sensing technologies such as aerial photography, Interferometric Synthetic Aperture Radar (InSAR) and Light Detection and Ranging (LiDAR) represent a powerful tool for landslide investigation [5]. However, getting ready landslide maps is critical for landslide study. The use of LiDAR-derived product’s has proven an effective technique for landslide recognition and capturing [9]. Nevertheless, not so much effort have been put in studying or reviewing the advances of this technique on landslide events. Hence, this paper attempt to review the application of multi-resolution of remote sensing technique in landslide study which focussing on landslide activity inventory mapping.

2. Classification of Remote Sensing Methods for Landslide Studies
Remote sensing for landslide studies is broadly recorded in the recent literature [5]. As stated by Michoud et al. [13], three (3) types of remote sensing methods were divided i.e. passive optical sensors, active optical sensors, and active microwave sensors.

2.1 Passive optical sensors
Passive optical sensors exploit the visible region of the electromagnetic range, such as visible,Near Infrared (NIR), and shortwave infrared system which given by hyperspectral images [5]. In landslide studies, three (3) types of passive optical sensors data that mainly used including ground-based imaging, aerial photographs, and satellite imaging. Table 1 describes the advantages and disadvantages of these three techniques.

| Techniques            | Advantages                                                                 | Disadvantages                                                                 |
|-----------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Ground-based imaging  | • High resolution for both spatial and temporal                              | • Limited coverage on gentle slope area                                        |
|                       | • Large coverage on hilly area                                                | • Inter-visibility is required                                                 |
|                       | • Low cost technique                                                         | • Environmental impacts (shadows in the pictures, not working in night)       |
|                       | • More flexible (i.e. easy data acquisition and high portability)             |                                                                              |
| Aerial photographs    | • Very high coverage especially on gentle slope area                          | • Limited temporal resolution                                                  |
|                       | • Availability of historical record                                           | • Inter-visibility is required                                                 |
|                       | • Very high spatial resolution                                                | • Others: low coverage in steep slopes and cliffs area                        |
| Satellite imaging     | • Very large spatial coverage                                                | • Low spatial resolution of historical images                                |
|                       | • Low cost data especially for low resolution images (Landsat, ASTER)         | • Low temporal resolution for some sensors                                    |
|                       | • Availability of historical record                                           | • The accuracy of data depending on the sensor                               |
|                       |                                                                              | • Inter-visibility is required                                                 |
|                       |                                                                              | • Low coverage in steep slopes and cliffs area                                |
|                       |                                                                              | • Present of atmospheric effect                                                |
|                       |                                                                              | • Expensive for commercial satellites                                         |
|                       |                                                                              | • Geometric distortions                                                        |

2.2 Active optical sensors
Unlike passive remote sensing technique, active optical sensors have their own particular radiation source. It collects three-dimensional coordinate data from reflected objects that useful for many applications. LiDAR is one of the technique that falls in this category. The basic concept of LiDAR measurement is fairly straightforward. LiDAR works by measuring the distance or range between a sensor and objects which is always based on precise time measurement. Travelling time is measured and the 3D coordinates (i.e. latitude, longitude, and elevation) of the reflected objects are registered. The result from the measurement procedure is a point cloud with randomly distributed laser points in elevation and position which depend on the scanning pattern. As mentioned by Zhong et al. [14] cited
from Starek et al. [15], LiDAR technology has been filled with various platforms such as airborne LiDAR also known as Airborne Laser Scanning (ALS), terrestrial LiDAR, mobile LiDAR, and indoor LiDAR. Airborne LiDAR uses a laser sensor attached on an aircraft or helicopter in order to get the distance of object from sensor. This technique able to gather three-dimensional (3D) data of objects in a large area [14][16]. However, only top of objects covered by airborne platform and lack of corresponding façade information [14]. Meanwhile, terrestrial LiDAR also called Terrestrial Laser Scanning (TLS) works in local scale area [5][17]. TLS provide shorter ranges and produce very high density of point clouds rather than airborne LiDAR. The combination of these two (2) platforms will gather full picture or information of object surfaces, both on the top side and façade side [14]. This combination was applied in many field of studies: (a) disaster such as landslide studies, flood studies (b) forestry applications such as biomass estimation [18], and (c) 3D object reconstruction [19].

3. Landslide Characteristics
Landslide is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity [20]. Landslide happen when part of a natural slope is fail in supporting its own weight [21][22]. The event of landslide is the result of a complex field of forces towards the mass of rock or soil on the slope area. Two (2) determinative parameters that cause the landslide: (i) an increase of shear stress, and (ii) a decrease of material strength [23]. The different kinds of landslides can be classified by the sorts of material involved and the type of movement [1]. It can move by falls, topplings, slides, flows, spread, and combinations of these movements. Varnes’ 1978 was produced which classify the landslide types based on material involved and mode of movements where have been globally used in landslide studies. Another broadly recognized landslides classification is based on the velocity of the movement material [20]. Besides that, landslides also can be categorized regarding their state of activity [24]. As mentioned by Cruden and Varnes [20] which revised by Jones and Lee [25], eight (8) groups of mass movements have been established which are active, suspended, dormant, inactive (i.e. abandoned, stabilized, anchored, and ancient) (Table 2). Besides that, classification of activity based on vegetation cover also produced by Evans et al. [26] i.e. (i) totally bare of vegetation (2 – 3 years old); (ii) partially bare of vegetation (between 2 – 3 and 30 years old); (iii) completely covered in grasses (more than 15 years old); and (iv) covered in shrubs and/or trees (more than 25 years old).

| Activity | Description |
|----------|-------------|
| Active   | Currently moving, or a currently unstable site such as an eroding sea-cliff or a site which displays a cyclical pattern of movement with a periodicity of up to 5 years. |
| Suspended| Landslides and sites displaying the potential for movement, but not conforming to the criteria for ‘Active’ status. |
| Dormant  | A landslide or site that remains stable under most conditions but may be reactivated in part or by extreme conditions. |
| Inactive | A landslide or site of instability which is stable under prevailing conditions as follow:  
Abandoned: A landslide which no longer affected by its original cause and is no longer likely to be reactivated. For example, the toe of the slide has been protected by a build up of material, such as floodplain or beach;  
Stabilized: A landslide which has been protected from its original causes by remedial measures;  
Anchored: A landslide that has been stabilized by vegetation growth; and  
Ancient: An inactive landslide developed under climatic, environmental or geomorphological conditions different from those prevailing at present. |

4. Landslide Inventory Mapping
Generally, a landslide inventory map provides basic information such as location of mass movements and the date of occurrences. Preparation of landslide inventory map is an imperative procedure of
landslide hazard study. As stated by Singroy [27], majority of landslide study accomplished by remote sensing technology to date falls into the category of inventory mapping. In general, the scale of landslide inventory map based on user requirement. The scale of map i.e. small-scale, medium scale, and large-scale was summarized in Table 3:

Table 3. Summarization of the landslide inventory component based on different scale

| Type          | Source of information                                                                 | Attribute                                                                 |
|---------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Small-scale   | Compile landslide archives (public or private organisations, journals, interviewing experts) [28] | Location of landslides                                                    |
|               | Aerial photograph analysis [29]                                                        |                                                                            |
| Medium-scale  | Systematic interpretation of aerial photograph with integrating of field check data     | Location of landslides, Original mass, volume and averaged velocity is recorded |
|               |                                                                                       | Data about damages (i.e. minor, major)                                     |
|               |                                                                                       | Minor and lateral scarps may be distinguished                              |
| Large-scale   | Interpretation of high resolution imageries, DTM, and local field data [30]             | Mapped landslides may be divided into its components: scarp, rupture surface and mass or deposit |
|               | Combining of high resolution data and analysis of literature [31]                       | Mass volume and average velocity is estimated and recorded                |
|               |                                                                                       | Total area of each landslide type                                          |
|               |                                                                                       | State of activity                                                         |
|               |                                                                                       | Detail data about damages                                                  |
|               |                                                                                       | Historical data                                                           |
|               |                                                                                       | Volume                                                                    |
|               |                                                                                       | Travel distance                                                           |
|               |                                                                                       | Date of occurrence                                                        |

5. Landslide Activity Inventory Mapping in Vegetated Area
As studied by number of authors, mapping of landslide in high dense vegetation is difficult. Large number of research were conducted by utilizing the data derived from ALS or TLS in landslide studies (i.e. landslide detection, susceptibility, hazard, risk) integrating with other remotely sensed data. This section describes the use of multi-resolution remote sensing data as landslide bio-indicator specifically for landslide activity inventory mapping. Soeters and Van Western [32] have identified landslide types based on vegetation characteristics. Rockfall movement normally characterized by linear scars in vegetation along frequent rock-fall paths while rotational slide has clear vegetation contrast with surroundings. This paper further reviews the related vegetation anomalies as indicator of landslide activity from previous findings as shown in Table 4.

According to Table 4, five (5) vegetation anomalies have been identified. Each anomaly consists of related vegetation variables. The first type of vegetation anomaly is tree irregularities or disrupted trees [40][33]. As investigated by Razak et al. [33], High Density Airborne LiDAR (HDAL) data was used in extracting the related vegetation variables (i.e. tree position, tree height, and inclination angle). These variables were successfully used for parameterizing tree growth anomalies such as tree dissimilarities and tree inclinations. They conclude that tree height is much lower in landslide area rather than stable areas. The tree inclination also more inclined in landslide area. Wang et al. [34] used Random Sample Consensus (RANSAC) based robust stem reconstruction method in identifying the tree inclination angle. Good accuracies obtained when compared to reference data that
measured manually. The second type of vegetation anomaly is tree crown gap. Gap indicator function (refer Table 4) was used in deriving tree crown gap [6].

| No. | Vegetation Anomalies                      | Related Vegetation Variables                                                                 | Previous Findings                                                                                                                                 |
|-----|-------------------------------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| 1.  | Tree irregularities and tree inclination  | Three (3) related vegetation variables identified in the study[33]:  
1. Tree position,  
2. Tree height, and  
3. Inclination angle.                                                                 | Tree height is lower and dissimilar in the landslide than in the stable areas.              |
|     |                                           | Stem curve modelling and quantification using RANSAC based robust stem reconstruction method and a Frenet-Serret formulas [34]. | Trees are also more inclined in the landslide area than in the stable area.                |
| 2.  | Tree crown gap                            | The canopy gap identified by using gap indicator function, $G$ [6]:  
$$G(x, y) = \begin{cases} 
\text{if } CHM(x, y) < a \\
\text{otherwise}
\end{cases}$$ (1) | The research introduced the method for assessing the inclination angle, curvature, and torsion along the tree stem for shallow landslide activity detection. |
|     |                                           | Three mapping methods [35]: i. thresholding,  
ii. per-pixel, and  
iii. per-object supervised classification.                                                      | The gaps between the trees are larger.  
The shapes of canopy gaps varied depending on the landslide types:  
i. Rock falls resulted in gaps that are elongated in the downslope direction, and  
ii. Complex landslide (rotational landslide followed with earthflow) are likely to produce small gaps that are scattered over the area. |
|     |                                           | A novel method in classifying the shape of gaps using landscape indices and multivariate statistics [36]. | This research focused on the assessment of canopy gap derivation method. The performance of CHM-based thresholding was exceeded by that of other methods. |
| 3.  | Root Strength Index                       | The root strength index was used in indicate the rate of landslide [37]:  
$$RST = H \times \sqrt{D}$$ (2)  
Where $RST$: the root strength index, $H$: estimated tree height, $D$: estimated tree density. | Canopy openings of gap type 3 (the largest gaps that were more regular in shape) were observed in the study area indicate that landslides or clear cutting were potential reasons for these areas. |
| 4.  | Trunk characteristics                     | - Tree with curved trunks [38], and  
- “Drunken trees” [33].                                                                                                               | Increase of the root strength index will decrease the rate of landslides. Root strength improved the prediction of shallow landslides. |
|     |                                           |                                                                                                                                       | Curved trunks cause by soil creep activity.                                                |
The finding clearly shows that landslide area always produces large gap between the trees. The pattern of the gap also varied based on the landslide types. Wu et al. [36] demonstrated a shape-based methodology for gap classification by using landscape indices and multivariate statistics from aerial photograph. They discovered that landslide was a potential reason for large canopy gap. This study can be improved by integrating the aerial photograph and LiDAR point cloud in determining the canopy gap. Next, root strength index was proposed by Iwahashi et al. [37] for predicting the rate of rainfall-induced landslides Hofu region, Japan. This index derived from tree parameters including tree height, tree diameter, and density of tree stands. They conclude that the rate of landslide decreased by increasing the root strength index. This index also highly significant in predict the shallow landslides. Besides that, trunk characteristics also associated with landslide activity. Razak et al. [33] and Menashe [38] found that curved trunk also known as “drunken trees” usually caused by slow or gradual soil creep. This anomaly was successfully parameterized from tree inclination angle by using HDAL. Menashe [38] has described several pattern of the trees as an indicator of landslide activity as shown in Table 4.

6. Conclusion
Landslides are among the most dangerous natural disasters. A lot of organisations including government and academic institutions have endeavored for quite a long time in assessing the landslide hazard and risk at any condition. This paper has reviewed a different method of remote sensing technique that can be applied for landslide study followed by description on landslides and landslides activity inventory mapping. The role of vegetation also cannot be indisputably. Vegetation anomalies can provide better understanding on landslide activity. The characteristics such as curved trunks and canopy gap need to be further explored especially in parameterize the indicator using multi-resolution remote sensing data.

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