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# Application of Unmanned Aerial Vehicle (UAV) in Terrain Mapping: Systematic Literature Review

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**Abstract:** Unmanned Aerial Vehicle (UAV) is an advanced technology that can be control remotely. It hovers up in the air and travel with different height and distance depending on the capability of the UAV. Originally, this technology was invented for military practice. Now, the innovation of UAV is growing and have contribute to various field including terrain mapping in surveying work. Carrying out mapping task in terrain such as mountain, valley, plateau, or rainforest can be a difficult task in-terms of time, practicality and cost. Another challenge is when the survey area is permanently clouded over and the limited availability of aircraft platforms and the orbit features of satellites causing difficulties to obtain high quality photos. Therefore, there are much research that used UAV technology to do mapping work and obtain Digital Terrain Model (DTM), Digital Surface Model (DSM) and Digital Elevation Model for various purposes. In this study, systematic literature review using thematic analysis methodology was used to review, evaluate and combine relevant literature review. The aim of this study is to categorise the application for terrain mapping using UAV and also to identify the system and result improvement of UAV during the usage in terrain mapping. From the thematic analysis, two themes which are understanding the earth structure with the subtheme of geotechnical study, geomorphological study and flood study and UAV system improvement with the subtheme of accuracy assessment, accuracy enhancement and resolution were formed.

**Keywords:** Unmanned Aerial Vehicle (UAV)

## 1. Introduction

New high-tech devices that are available today are necessitates by digital mapping technology and it result in a higher data accuracy (Yuansheng, 2018). Unmanned Aerial Vehicles (UAVs) is a product from the innovation of modern technology and now are known as a competitive data gathering equipment that can be controlled from a distance (Koeva et al., 2018). Military goals and other application in different field had catalyst the evolution of UAV including the innovation of its platform and its system. Nowadays, a wide application of UAV in the geomatic study can be seen despite the fact that this technology has been used in this field approximately around thirty years ago (Nex & Remondino, 2014) Challenges in terms of devices and terrain condition might be encountered during mapping work. A number of conventional devices used to produce Digital Terrain Model (DTM) and Digital Surface Model (DSM) have several disadvantages in terms of cost, time taken and practicality (Yazid et al., 2019). Terrain conditions and areas might vary. Depending on these condition, different challenge might be encountered. In mountain or natural terrain, several obstacles arise when conducting geophysical survey due to potential elements that might cause difficulties in surveying work including types of energy source, reserve forests, disturbance from wildlife, and extremely wavy terrain conditions (Ismail et al., 2018).

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This study aims to categorise the application for terrain mapping using UAV in different study field and to identify the system and result improvement of UAV during the usage in terrain mapping. Therefore, this study will focus on analysing previous research through a comprehensive systematic literature review method to assess the UAV applicability in terrain mapping

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## 2. Methodology

To ensure this study will achieve its objectives, a search for related articles that linked to the application of Unmanned Aerial Vehicle (UAV) in terrain mapping using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) will be conducted. PRISMA that was published in 2009, aimed at improving systematic review reporting (Page et al., 2021). This method provide transparent establishment of research question, making it a widely used technique in medical and management-related study (Ali et al., 2021). Figure 1 shows the research flow chart methodology using PRISMA method.

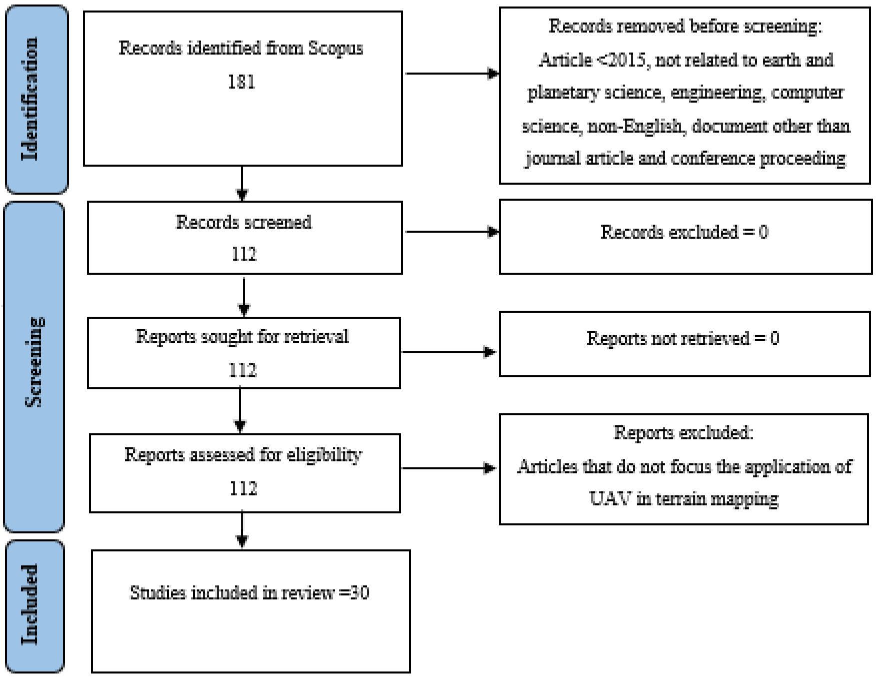


**Fig. 1 - Research flow chart methodology using PRISMA**

### 2.1 Screening and Eligibility

Articles are selected from SCOPUS database. The database platform provides filtering tools to refine researchers' research. This tool is helpful as it will help in narrowing down the number of documents by filtering out documents that are not related to the study. The filtration criteria are selected as in Fig.1.

### 2.2 Data Extraction

Using thematic analysis, the data from the identified documents will be extracted for analysis purpose. This method constructs a logical structure for researcher to relate a study from the theme identification with the whole study content (Alhojailan, 2012). Two steps to identify the main and sub theme are choosing data that aligns with the research objective and the output should be analysed for main theme and concept determination (Ali et al., 2021).

### 2.3 Testing Equipment

There are various of testing method using UAV in order to obtain terrain mapping. From a landslide study in Mayun Village, a DJI Inspire II UAV equipped with a Xemuse X4 lens was used to map the area. Few controls measure like maintaining the speed to 4.6 m/s and sustaining 85% of frontal side lap was by utilizing Pix4D capture double-gridded mission was done to give better outcome (Ahmad et al., 2021). Meanwhile, another study in Okeanos, use DJI Phantom 3 with a 3.61mm FC300X camera to capture 75 images in the area and then processed using Agisoft Photoscan software giving a total of 24 million points in a point cloud dataset (Valkaniotis et al., 2018).

An unstable rock mass risk assessment conducted at the Yumenkou tunnel entrance, Shanxi province, China use DJI Phantom Pro4 where it manages to be utilised within the study area and 500m further (Wang et al., 2021). Another geomorphology study in Spark Lake in Jiuzhaigou, China was performed by using two UAV and equipping each of it with GPS and IMU to record output in the process of acquiring images (He et al., 2021). Lastly, in a geomorphological study in Aktru River basin, Gornyi Russia the UAV used is the multi-rotor DJI Mavic Pro model while the images were processed through Agisoft Photoscan Software package (Hedding et al., 2020).

## 3. Results and Discussion

The systematic literature reviews have been organised into 2 main themes, which are understanding the earth structure and UAV system analysis where each of which caters to a different theme in which the notion of application of UAV in terrain mapping.

### 3.1 Understanding the Earth Structure

This theme emphasis on the application of UAV in different fields where it has helped researchers to study and understand the earth structure. Therefore, the sub theme selected will be based on these fields which consist of geotechnical study, geomorphological study and flood study.

In geotechnical study, UAV were used in order to do slope analysis and hazard assessment. Through a slope map, linear geological elements of slope map were identified (Piras et al., 2017). This will help to analyse the critical parts of slope that can lead to landslide. The further analysis from UAV data help to obtain slope angle which will be used for hazard identification (Zolkepli et al., 2021). A visualisation of 3D map from the data obtained through UAV was used to produce a 3D models of rock slope and then the stability of the slope is further analysed through software. The material parameters, failure criterion, and stability analysis method are entered to perform three-dimensional stability analysis and obtain a 3D global critical slip surface of the slope (Congress & Puppala, 2021). By combining output of thematic layers from high to low, identification of the most unstable area can be identified (Leo Stalin & Gnanaprakasam, 2020). Fig. 2 shows unstable area in active mine pit. A study by (Fang et al., 2021) utilised UAV to identify man-made terrace damage in loess plateau of China. The terrace damages were extracted using high-resolution orthophoto imagery and DSMs which will then be used to produce classification map for the damages (Fang et al., 2021). From map generation, researcher can obtain useful information such as soil leak area and decay length of the study area (Kim et al., 2019). Meanwhile, findings from (David Stewart et al., 2018) in New Zealand verifies that there are a number of event where UAV was deployed for earthquake, rockfall and stability assessment and cliff risk assessment.

Geomorphological study is listed as the subtheme of this study. From this subtheme, researcher can learn about earth surface and the relationship to its geological structure. A finding from (Šašak et al., 2019) shows that by data combination from TLS and UAV-SfM produce a high-resolution DEM that opens up new options for multiscale geomorphic modelling and segmentation, presenting a full nested structure of landforms and land surface processes. Small details such as a small 2cm flute, foreland channels, and human influences can be spotted using the DEM created with the help of a UAV (Ely et al., 2017) UAV are suitable to be used in 1 mountainous terrain covered in snow as it can capture a high-quality image under a windy condition up to 20m/s (Buhler et al., 2016). (Lytkin & Syromyatnikov, 2021) findings shows that orthomasaic produced managed to obtain polygonal features of the affected area because of thermocast effect. Meanwhile (Nahon et al., 2019) verifies that UAS-based DEM ables to gain morphological characteristics of foredune out of area coverage by Mobile Laser Scanning (MLS). Geomorphic changes after a natural disaster specifically flood, can also be detected using UAV. Flood cause fluvial deposition shifted including a large portion of the fresh fluvial accumulations (Langhammer & Vacková, 2018).

Another subtheme listed under this theme is flood study. Schumann et al. (2019) used the approach proposed by Schumann et al. for flood-fill modelling where it uses DTM data gain from UAV to create a floodplain elevation model to represent the flooded site. UAV face difficulties in generating full reproduction of the channel bottom but it can generate the bathymetry of shallow stream. Thus, with this limitation, the extent of the flood spill can be observed during the flood event was well-matched by the reconstruction of the flooded region generated from the DEM (Langhammer & Vacková, 2018). Flooding and the damage of infrastructure happened primarily in agricultural areas and near river facilities (Kim et al., 2019).

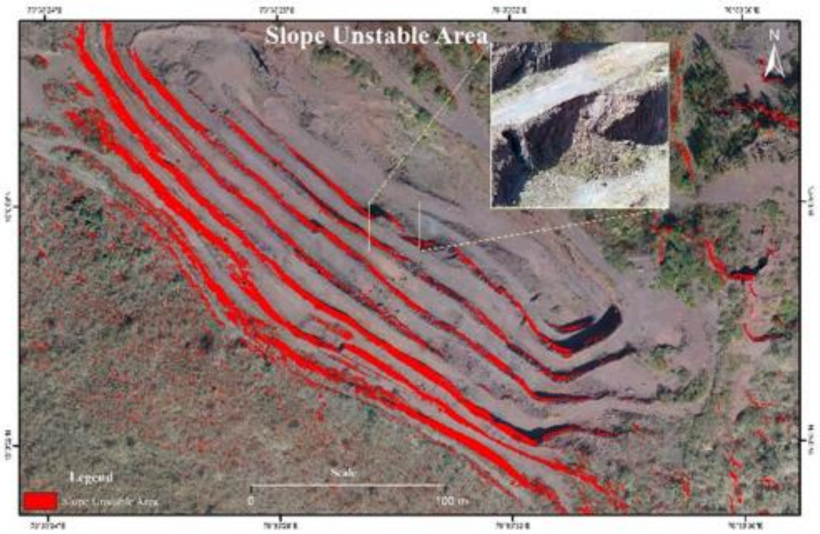


**Fig. 2 - Unstable area in active mine pit (Leo Stalin & Gnanaprakasam, 2020)**

## 3.2 UAV System Analysis

The research analysed in this theme focus on the technical part of UAV revolving around the approach used to understand and improve the system during the usage and the result from UAV mapping. Therefore, the selected subtheme for this theme are accuracy assessment, enchasing accuracy and resolution improvement.

Many researchers conducted accuracy assessment of the data and generated from UAV such as DTM, DEM, DSM and orthophoto in their study. This will help to ensure that the output from the experiment is accurate and reliable. To assess the systematic error, root mean square error (RMSE) can be calculated. A number of researchers used RMSE method in their study (Adams et al., 2018; Buhler et al., 2016; Mian et al., 2016; Nam-Bui et al., 2020; Nesbit & Hugenholtz, 2019; Šašak et al., 2019; Stark et al., 2021; Vieira et al., 2021; Wierzbicki & Nienaltowski, 2019; Yazid et al., 2019). The lower the RMSE value, the accurate the data. Different type of survey area can influence the accuracy of the data from UAV. It was found that generated DSM and DTM in forest area have lowest accuracy compared to plantation area and developed area due to obstruction that block rays from reaching the ground surface (Yazid et al., 2019). A study using a dense point cloud to analyse the accuracy of terrain mapping conducted by (Wierzbicki & Nienaltowski, 2019) finds that when the test areas have no vegetation, higher accuracy result can be obtain compared to thicket test area. Assessing the accuracy of DSM (Y coordinate) and the orthomosaic (X and Y coordinate) using georeferencing of bundle block adjustment (BBA) with Post-Processing Kinematic (PPK) method give a high accuracy result where the accuracy does not exceed 0.072m did not exceed 0.034m respectively (Žabota & Kobal, 2021). Researcher have also compared data from other mapping equipment to assesses the precision of data output by UAV. (Nesbit & Hugenholtz, 2019) examined exceeding 150 scenarios with various mix of oblique and nadir camera angles, picture overlap settings, and flight line orientations to a reference dataset obtained with TLS to see how imaging angle effects accuracy and detail of UAV–SfM 3D outputs. A comparison of accuracy from UAV mapping and TLS mapping was done and it was found that UAV are more accurate than TLS for terrain mapping (Gruszczyński et al., 2017). Accuracy result between different UAV grade is comparable depending on selected data sampling and processing parameters. A reliable DEM accuracy can also be obtained when operating the UAV in a lower flight altitude (Fang et al., 2021). The results from (Fang et al., 2021) demonstrate that the DSMs and SDMs for snow depth mapping were acquired with $\leq 0.25$ and $\leq 0.29$ m accuracy when exposed under full sunlight. To assesses the accuracy of DSM, elevations can be compared to ground control points collected with a differential GNSS (Vieira et al., 2021). Data accuracy can also be done by comparing the position error from drone mapping with traditional mapping (Kim et al., 2019).

Another subtopic in this theme is enchasing accuracy where the analysed articles discussed about various method to increase the accuracy of the UAV output and the system itself. The UAV Findings from (Nesbit & Hugenholtz, 2019) show that, augmenting parallel-axis (nadir) picture obstruct with oblique images decreases or eliminates systematic dome errors in UAV–SfM datasets. Meanwhile, genetic algorithm-based view planner for UAV terrain modelling generates optimum flight paths that improve the accuracy of model regeneration by up to 43% compared to the basic grid, as well as increasing model completeness (Martin et al., 2016). A white reference target, as well as upward and downward shortwave radiation data from broadband silicon pyranometers workflow technique, were used to create an accurate albedo product by utilising UAV and other mapping equipment (Ryan et al., 2017). Furthermore, the incorporation between UAV photogrammetry and high-quality IMU/GNSS data in sandy coastal area gives a vertical accuracy at least 15cm (Kumar, 2018).

The next subtheme is resolution improvement. In this subtheme, ways to increase the resolution of image. Flying UAV in a lower altitude will increase the image gain from the survey. A study by (Fang et al., 2021) shows that images increase from 80 to 247 when flight altitude decrease from 250m to 50m. Flying the drone over a lower altitude have also increase the orthomosaic resolution and DEM compared to higher altitude (Battulwar et al., 2020). The drone specification such as the focal length and sensor size also will affect the image resolution. (Nam-Bui et al., 2020) used a DJI Phantom 4 Pro commercial quadcopter with a 20-megapixel RGB camera with a focal length of 8.8 mm and a sensor size of 13.2 mm x 8.8 mm to take high-resolution aerial photography in their study. Cameras with bigger sensor size produce sharper photo because of the high ISO speed and signal-to-noise ratio (De Marco et al., 2021). However, camera problem such as distortion and dark current (additional noise from camera) that can disrupt the photo resolution. To overcome this problem, lens distortion parameters identification and dark current subtraction can be done (Jakob et al., 2017). (Thiele et al., 2022) overcome distortion problem using open source hylite toolbox. High resolution photo can also be produced when there are dense point cloud and no relevant gaps in the survey area, leading to precise representation of the terrain surface (Vieira et al., 2021).

## 3.3 Findings Summary

As a conclusion, UAV is an important tool that have been used to produce maps in 3 different study which are geotechnical, geomorphological and flood study.Through the 3D module produced, researcher able to analyse the stability of rock slope while the DSM and orthophoto can produce damage classification map. In geomorphological study, DEM used to generate models representing landform structure and process, focusing on small detail. It also detects changes after flooding and can be visualised through 3D map. As for flood study, DTM will be utilised to produce elevation profile while DEM can reconstruct flooded region.

To ensure that UAV system and the data produced are reliable and accurate for terrain mapping, methods of accuracy assessment, accuracy enhancement and resolution improvement were also identified through previous research. There are several accuracy assessments that can be conducted depending on the types of error that need to be assessed. The common systematic error assessment is RMSE method. Accuracy assessment can also be conducted by setting variables such as the height of flight altitude, type of survey area and the lighting condition of the area. It can be sum up that lower flight altitude, low vegetation area and good lighting condition results in higher accuracy in producing maps. A method to evaluate DSM can be done by using the integration of BBA and PPK method. Other accuracy analysis that can be done is comparison of data obtain from UAV and other mapping equipment or by traditional mapping. To enchase the accuracy, findings from previous research shows several methods can be applied such as augmenting parallel-axis picture block with oblique image, application of UAV genetic algorithm-based view planner for UAV terrain modelling, implementation of white reference target, as well as upward and downward shortwave radiation data and combination UAV photogrammetry and high-quality of IMU/GNSS data. Lastly, the resolution of UAV output can be improved through flying the UAV in lower altitude, use UAV equipped with camera that have large sensor, overcome distortion problem by conducting lens distortion parameters identification, dark current subtraction or use hylite toolbox. Better resolution also can be obtained when there are dense point cloud and no relevant gaps in the survey area.

## 4. Conclusion

This study was conducted with the aim to categorize the application for terrain mapping using UAV in different study field. This research also aims to identify the system and result improvement of UAV during the usage in terrain mapping. Through this study, 2 themes were organized which are understanding the earth structure and UAV system analysis. From these themes the area of study for the application of UAV in terrain mapping which are geotechnical study, geomorphological study and flood study was identified while ways to increase the quality as well as assessment of data accuracy and UAV system are figure out through the subtheme of accuracy assessment, accuracy enhancement and also resolution improvement. It is suggested that researcher analysed as many as possible article or research paper that was related to the study. This can be done by widening the subject area that are relevant to the study or by including research publication that are less than 2015. This helps in-depth understanding and identification of other possible application of UAV in other area of study and also the enhancement of the system and output. Researcher who are interested in conducting a systematic literature review using quantitative methodology can conduct a bibliometric analysis.

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