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Review Article

Towards the Assessment of Skid Trails in Logged-over Forest Using Drone Technology: A Review for the Timber Industry in Malaysia

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Abstract: Following the approval of the Detailed or Road Plan (DP) by the Forest Department of Sarawak (FDS) and subsequent field reconnaissance; the Licensee or the appointed contractor shall prepare the Reduced Impact Logging (RIL) Workmap for each harvesting block of timber. The skid trail layout within the block is part of the preparation of the RIL Workmap and skid trail alignment is one of the features in RIL Workmap. Skid trail planning involves making several decisions to avoid sensitive areas and optimise access to harvestable trees. The problem faced by Forest Management Unit (FMU) licensees is that there is no locally proven mechanism to assist them in identifying skid trails that can ensure minimal route length and high accessibility to harvestable trees. Proper planning of skid trails as timber harvesting routes in forests is an ongoing challenge and important to minimise environmental damage. Therefore, a study to identify skid trails in FMU is essential to assist licensees in their harvesting plan. The application of drone technology will be used as a tool to capture the image of skid trails in FMU before re-entry of the block for the harvesting process. This study would look at the single parameter affecting the skid trails which is the slope. Thus, this study will focus on the answer of; how the application of drones in identifying skid trails can assist FMU holders. In Sarawak, this research is very limited and still new, particularly in the operation of drones to identify skid trails. This additional scientific finding on the application of drones to identify skid trails in the logged-over forest, would help FMU in planning and practicing the RIL Guideline. Besides that, this study is also important to create innovative approaches using drone technology in the forest industry.

Keywords: skid trail; logged-over forest; drone technology; slope; RIL; UAV

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1. Introduction

The Malaysian forests have been subjected to systematic management since the establishment of the Forestry Department in 1901. Through the development of ecologically and environmentally sustainable forest conservation and management practices, efforts have been made to ensure forest regeneration and long-term productivity (Moktshim, 2020). Malaysia has gained global recognition for successfully striking a balance between conservation and development. The country has preserved 50% of its total land area as tropical forest while simultaneously cultivating a thriving timber export industry that is admired by its Asian counterparts (Hickson, 2021).

As a significant producer and exporter of tropical timber products, Malaysia has achieved a total export value of RM17.81 billion (US$4.4 billion) from January to October 2020, as reported by the Department of Statistics Malaysia and the Malaysian Timber Industry Board. This accomplishment is particularly noteworthy given the context of the global pandemic. Malaysia's timber product exports have consistently averaged around RM20 billion (US$4.9 billion) annually over the past decade, underscoring the industry's crucial role in the country's economy (Hickson, 2021).

The progression of forest management studies in Malaysia has been documented through the country's chronological endeavours toward becoming a developed nation. Forest resource development is a key aspect of forest development planning and resource utilisation, focusing on the impact on the environment and human life. While economic development is emphasised, the primary concern remains in the quality of life while striving for improved economic standards (Moktshim, 2020).

As a developing nation, Malaysia requires resources to kickstart and sustain its development initiatives. Forest resources play a vital role in the country's progress by supplying raw materials that fuel various economic activities, including agriculture, mining, forestry, energy, and tourism. Economic development influences environmental processes and responses, leading to changes in process frequency and intensity, the emergence of new processes, and the generation of waste. Environmental quality can be assessed by monitoring changes in key environmental parameters that characterise major forest subsystems such as air, water, land, and ecology (Moktshim, 2020).

Forests play a vital role in global and regional ecosystems, profoundly impacting human lives and livelihoods in diverse ways. Nonetheless, there is a concerning decline in both the quality and quantity of forests worldwide. The implementation of sustainable forest management practices, in conjunction with the integration of geospatial technologies, holds significant promise for the conservation and monitoring of this invaluable renewable resource. Geospatial technologies, including satellite imagery and Unmanned Aerial Vehicles (UAVs), provide essential tools for evaluating forest extent, density, composition, plantations, and grasslands, as well as for monitoring changes and assessing damages. Change monitoring encompasses a range of activities such as afforestation, reforestation, forest cover transformations, and evaluating damage resulting from forest degradation, encroachment, shifting cultivation, forest fires, pests, and diseases (Varghese *et al.*, 2022).

In recent years, advancements in Unmanned Aerial Vehicle (UAV) or drone technology have enhanced their usability and efficiency, making them a valuable tool for three-dimensional (3D) forest mapping. Drones offer a unique combination of high spatial and temporal resolution (Li *et al.*, 2019), which can significantly aid in the management of forest resources. Mapping forests in 3D at the individual tree level has become crucial for effective forest management and ensuring ecosystem sustainability. Conventionally, obtaining detailed information about harvestable trees required labour-intensive, time-consuming field inventories or surveys that were limited in accessibility. In this aspect, the use of drones to generate skid trails in previously logged forests proved to be beneficial for forest management and ecosystem sustainability. This approach eliminates the need for extensive manual labour and allows for a more precise and comprehensive assessment of the forest area. Hence, this study explores the concepts of drone technology and skid trails, while also delving into the timber industry in Malaysia. It proposes methods for evaluating skid trails in logged-over forests using drone technology, aiming to enhance forest management practices and promote ecosystem preservation.

1.1 Objective of Study

This paper focuses on three (3) objectives that are directly related to the research problem. These objectives include determining the slope and length of the skid trail in a block for timber harvesting through the utilisation of drone imagery, creating a 3D model of skid trails using a Geographic Information System (GIS) modelling software and identifying the skid trails that offer the shortest route length with optimal accessibility to harvestable trees.

1.2 Scope of Study

In order to achieve the first objective of this study, the slope, and lengths of skid trails were measured using drone imagery. The purpose of measuring the slope and lengths of skid trails was to compare with the information acquired from the licensee which were collected manually on the ground.

The operation of drones and the images captured using drone operation for mapping and 3D modelling were integrated with GIS information to accomplish the second objective. The software that were used for processing and analysing the data obtained include ArcGIS, Agisoft Metashape, Global Mapper and ANOVA.

In the third objective, 3D modelling for skid trails generated can illustrate the alternative skid trail routes to compare and determine the minimal route length that has high accessibility to harvestable trees. This result is important to justify the accessibility to harvestable or marketable trees and the length of the route of the skid trail from the stand site to the roadside landing which is needed for the Forest Management Unit (FMU) to plan whether the existing skid trails are relevant to be used (in terms of cost-benefit, time and manpower) or is there a necessity to propose new trails for extracting harvestable trees from stand sites to roadside landings.

1.3 Forest Management in Sarawak

In Sarawak, the State Government has mandated that all long-term Forest Timber Licensees must acquire Forest Management Certification (FMC) to ensure the sustainable management of natural forests and minimise negative environmental impacts. Reduced Impact Logging (RIL) plays a critical role in Sustainable Forest Management (SFM) by advocating for responsible harvesting practices and establishing guidelines for forest harvesting activities (FDS, 2019).

As outlined by FDS (2019), the Forest Management Plan (FMP) outlines the planned forestry operations such as inventory, yield estimation, harvesting, silviculture, protection, and monitoring within FMU. It sets the objectives, actions, and control measures, while also detailing mechanisms for FMU holders to involve relevant communities and stakeholders in FMU management. The FMP should encompass a strategic or long-term management strategy and undergo periodic reviews to incorporate new insights, experiences, and changing circumstances.

The FMP serves as a legal document for long-term FMUs and is a prerequisite under Principle 7: Management Plan of the Criteria and Indicators of the Malaysian Timber Certification Scheme (MCTS). FMU holders are responsible for drafting the document, which must be approved by the Forest Department before proceeding with the certification process (FDS, 2019).

1.4 Drone Technology

UAV also known as drones is a low-cost alternative in remote sensing technology and data analysis techniques nowadays (Norasma *et al.*, 2019). It was first introduced in the military for its surveillance during the war. However, now there are wide applications such as the forestry industry, agriculture (Roslim *et al.*, 2021), rangeland, weed mapping (Ya'acob *et al.*, 2022) and ecology research. Drone could be one of the solutions in getting higher resolution at an appropriate price, fulfilling the requirements of the spectral, spatial, and temporal resolutions desired, and real-time processing ability as well as diminish the influence of environmental effects as compared to other sensing techniques (Roslim *et al.*, 2021; Norasma *et al.*, 2019). In addition, drone imagery can capture data to generate a Digital Elevation Model (DEM) for further analysis. A DEM is a crucial spatial dataset in many GIS, representing ground elevation in a digital format. Within the literature, three commonly used terms are associated with this concept: DEM, Digital Terrain Model (DTM), and Digital Surface Model (DSM). A DEM specifically models the bare land surface, excluding trees, buildings, and other non-ground objects. In contrast, a DSM includes all elements such as buildings, trees, and bare ground. Meanwhile, a DTM is a broader term encompassing a DEM with additional terrain information like morphological features, drainage patterns, and soil properties. When focusing solely on height information, it is referred to as a DEM, which is essentially a subset of DTMs. (Zhou, 2017; Chaudhry *et al.*, 2021)

Drones could be an alternative to collect field data accurately. Drone technology has been recognised as a potential technology that can produce high spatial resolution imagery (< 1m) at a temporal frequency appropriate for timely responses in the production of actionable information (Elarab *et al.*, 2015; Abdul Kahar *et al.*, 2021) about crop and field statuses. The small drone can be easily flown and maintained with minimal training, making it a great option for users looking to advance farming activities by integrating agriculture with remote sensing technology (Cano *et al.*, 2017; Mohiden *et al.*, 2022). Drones can be categorised into two types; fixed-wing and multirotor. It is a potential substitute for satellite-based remote sensing and it has been acknowledged to generate high spatial resolution imagery and temporal frequency appropriate for timely responses. Table 1 indicates the comparison between multirotor and fixed-wing UAVs.

Table 1. Comparison between multirotor and fixed wing's UAV (Norasma *et al.*, 2019)

Type of UAV	**Payload (kg)**	**Flight time** (minutes)	**Benefit**	**Limitation**	**Example**
Multirotor	0.8–8.0	8–120	▪ Applicable with waypoint navigation ▪ Hovering capabilities Can hold a range of sensors from thermal, multispectral to hyperspectral cameras.	The payload may limit battery usage and flight time	DJI Inspire, Microcopter ARK OktoXL 6S12, Yamaha RMAX
Fixed-wing	1.0–10.0	30–240	▪ Better flight time ▪ Multiple sensors can be mounted	▪ Limited hovering capacity ▪ Lower speed is required for image stitching	Landcaster Precision Hawk, senseFly eBee

A drone can carry different payloads depending on its type. According to Roslim *et al*. (2021), drones are capable of attaching with various sensors such as hyperspectral, multi-spectral, and RGB (red-green-blue).

1.5 Skid Trail

Proper planning of skid trails as timber harvesting routes in forests is an ongoing challenge and important to minimise environmental damage (FDS, 2019). Therefore, a study to identify skid trails in FMU is essential to assist licensees in their harvesting plan.

As per FDS (2019), the annual working coupes primarily occupy areas within logged-over forests where logging roads have previously been established. Following the approval of the Detailed Plan/Road Plan by the relevant authority and completion of field reconnaissance, the logging operator is tasked with creating an RIL workmap for each specific logging block. This workmap initially displays the existing road/surveyed road alignment, locations of roadside log landings identified during field reconnaissance, and the proposed layout of skid trails within the block. Skid trails are planned to begin from the landing area and typically follow ridgelines. The permissible skid trail gradient is set at up to 20° (36%) with distances reaching one (1) km. In logged-over regions, the maximum gradient may reach 35° (70%), but distances should not exceed 30 m. Skid trails are prohibited within buffer zones, protected areas, and zones of High Conservation Value. Under RIL, the acceptable skid trail density ranges from 80-90 m per ha , and existing skid trails should be utilised whenever possible.

According to FDS (2019) and De Armond *et al.* (2021), roadside landings should be situated on both sides of forest roads to prevent the transportation of logs across or along the road. These landings should be located adjacent to spur/ridges intended for use as primary skid trails and should be positioned in well-drained areas. Sites requiring significant earthworks should be avoided, and landings must not encroach upon buffer zones, particularly Stream Buffer Reserves (SBR). The spacing of landings should be planned to ensure that maximum skidding distances do not exceed 1,000 m.

In terms of tree selection criteria, specific guidelines must be adhered to as outlined by FDS (2019). To be eligible for harvesting, a tree must be situated within the harvesting block, outside buffer zones, and away from steep slopes (with gradients exceeding 35° or 70%). The selected tree must not belong to any protected species categorised under Totally Protected and Protected Plants. Additionally, it should not be a mother tree or PCT and must have the capacity to yield at least one merchantable log measuring over 3.6 m in length. The distance of the tree from the skid trail should not exceed 60 meters along the ground, although this can be extended to 100 m under favourable terrain conditions to minimise environmental impact.

Presently, there is no established local mechanism for identifying skid trails with optimal accessibility to harvestable trees within the designated logging areas. The planning of skid trails within the block forms an integral part of preparing the RIL Workmap. Skid trail planning necessitates careful decision-making to steer clear of sensitive areas such as rivers or streams, buffer zones and High Conservation Value areas, and to optimise access routes to harvestable trees (FDS, 2019).

Based on a study conducted by Parsakhoo *et al.* (2017), the study encompassed an analysis of a network of roads spanning a total length of 31 km, focusing on the identification of start and target nodes, mapping slope stability for the design of skid trails, and the design of optimal skid trail routes. By utilising GPS data collected during field surveys, potential routes between start and target nodes on stable terrain were identified and analysed using the ArcGIS Network Analyst tool. The study also involved route network analysis, where a service area tool in GIS was employed to assess accessibility and tree positioning along the skid trails. The results derived from the network analysis, facilitated by a decision support system and technical parameters, emphasised the importance of comprehensive data in effectively designing skid trails within forest environments. This data encompassed information on slopes, streams, soil stability, as well as the positions of marked trees and log landings. According to Sales *et al.* (2019), the Census Inventory involved planning scenarios that focused on utilising "for harvest" trees to minimise the total skid-trail distance. In addition, by using the Network Analyst tool in ArcGIS® software, yard locations and tree-yard allocations were determined for each scenario. This tool employs the Dijkstra algorithm (DA) to calculate the shortest route between two points. The DA algorithm proved to be more effective than the existing planning method, resulting in reduced skid-trail distances, lower trail and road densities, and an increased number of trees within the optimal extraction distance for the analysed scenarios.

2. Methodological Framework

The proposed method of this study is divided into three main stages which are site selection, plot establishment as well as data collection and analysis. The details of the methodological framework are illustrated in Figure 1. The application of drone technology will be used as a tool to capture the image of skid trails in FMU before re-entry of the block for the harvesting process. The main parameter considered for mapping the terrain stability in the skid trails for this study is the slope. The research methodology that will be applied in the study is the establishment of two plots by selecting two blocks in one FMU. The size of one established plot is estimated at 100ha. This study is essential to identify the skid trail types (main skid trail / secondary skid trail/feeder skid trail/breakout trail) for extracting harvestable trees to roadside landings using data analysed from drone mapping and GIS as the output to minimise the length of the route and increase the accessibility to harvestable trees. This study will acquire assistance from the FMU holder to provide relevant information for the data analysis. Information such as RIL map, tree Location map, comprehensive harvesting plan map, a summary of trees for protection within the coupe, a summary of the skid trail network and trees to be harvested for each individual block will be acquired from the FMU holder. The result of this study could be a mechanism for FMU to adapt to their RIL guideline practice.

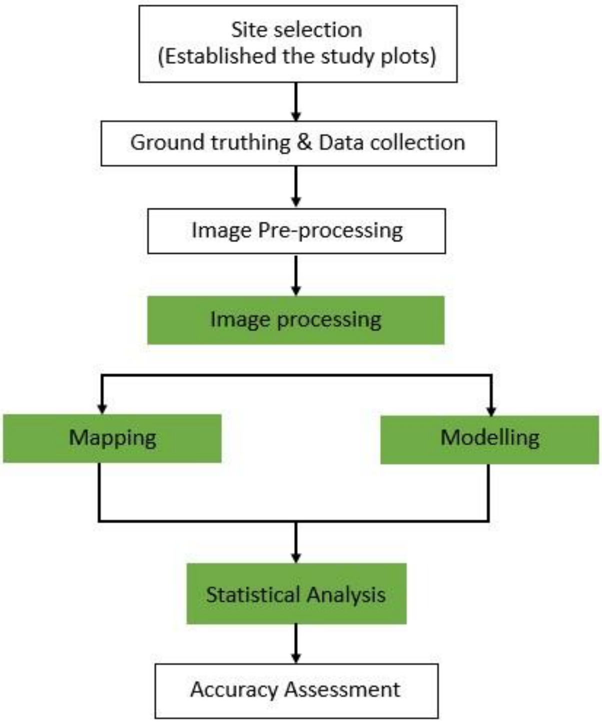

Figure 1. The methodological framework of the study.

Based on a study conducted by Parsakhoo *et al.* (2017), the application of network analysis tools revealed that the implementation of a new routing algorithm led to a 12.03% reduction in route length within the study area. Another approach or method that has been used is by application of Lidar technology. According to Đuka *et al.* (2017), the utilisation of laser scanning technology in conjunction with forest digital maps, supported by the refinement of appropriate algorithms, has the potential to optimise skid trail networks and decrease the number of trees that need to be cut during network construction. The length of skid trails and the number of trees to be felled are primarily influenced by the spacing between trails, which is in turn determined by the logging and wood extraction methods employed.

However, for this study, the usage of the tool will be limited to the capacity of the drone itself as the technology to capture the imagery data. It is known that incorporating Lidar technology in mapping can yield more precise results. Nevertheless, this study will solely concentrate on data gathered through drone imagery without utilising Lidar technology. This decision is made in light of the operational costs associated with mapping skid trails for the licensee if they opt to adopt this approach in the future. Therefore, selecting a drone with excellent aerial photography capabilities is crucial. For this study, a DJI Mavic 3 drone will be used to capture the aerial imagery due to its reliability and cost.

2.1 Proposed Study Site

The study area is located at Gerenai FMU in Miri, Sarawak which covers an area of 148,305 ha as depicted in Figure 2.

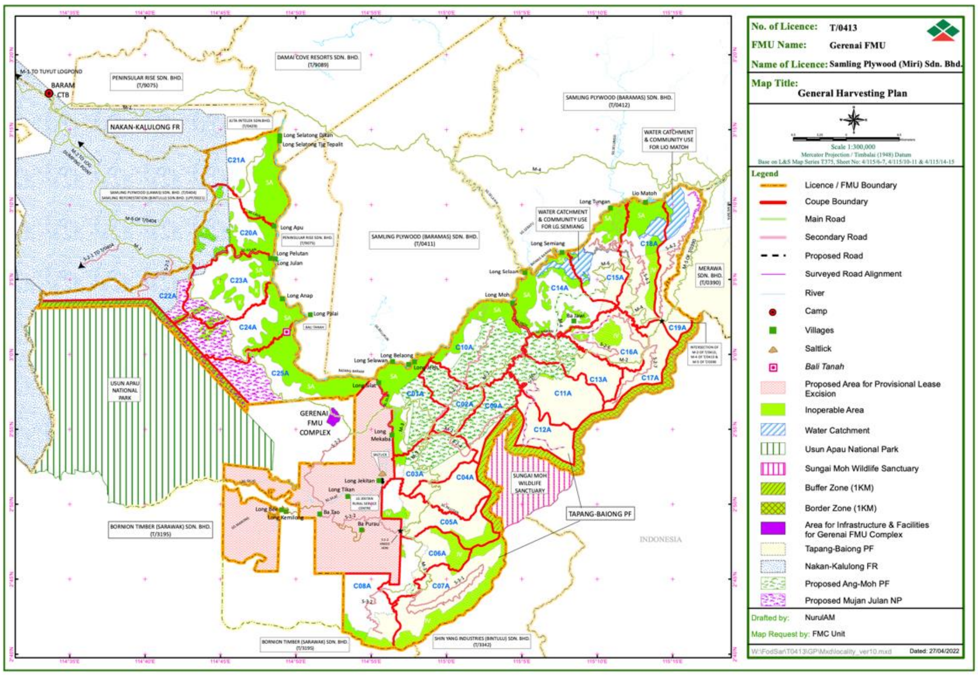

Figure 2. Study area.

2.2 Plot Establishment

Two harvesting plots will be established by selecting two blocks in the Permit to Enter Coupe (PEC) that will undergo the harvesting stage. The size of each plot is approximately 100 ha with existing skid trails for re-entry of block for harvesting. The re-entry of blocks (established plot) using the existing skid trails is expected to be carried out in the second quarter of 2023 during the harvesting period of timbers. The Permit to Enter Coupe (PEC) system ensures that the Licensee complies with the DP/RP and pre-felling requirements outlined in the FMP before starting the harvesting operation. The PEC process consists of five operational stages that must be submitted for approval to FDS in multiple steps:

Operation 1: Cut, and demarcate Coupe boundaries, Block boundaries, buffer zones and protection zones

Operation 2: Alignment and survey of proposed roads (where required), road construction, road repairs and upgrading

Operation 3: Identification, enumeration and marking of harvestable trees, marking and recording of trees for protection

Operation 4: Skid trail alignment, survey and construction. Preparation of RIL plan

Operation 5: Block endorsement for harvesting operation, permitted up to 9 months

The Harvesting Block is situated in the productive forest zone designated in the forest zoning process and the relevant Forest Management Plan. The Licensee or their designated contractor has conducted a pre-felling inventory in the Block and submitted the timber stock data and summaries to FDS. The Licensee has formally applied for harvesting in the Block following Operation 5 of the PEC system (FDS, 2019).

2.3 Data Collection and Data Analysis

The slope at the skid trail is the main parameter to be selected for this study. Information on the slope at skid trails is collected before and after the re-entry of the block for harvesting. The purpose of collecting data before re-entry is to evaluate the skid trail gradient compliance towards the RIL Plan. The purpose of collecting data after harvesting is to evaluate the damage or effect of re-entry towards the slope. Based on RIL Guidelines, skid trails with a maximum gradient of 35° (70%) over a maximum distance of 30 m are permitted to be used. Comparison and analysis of slope between the aerial imagery and secondary data along skid trails will be based on a one-way analysis of variance (ANOVA).

Analysis of variance (ANOVA), often abbreviated as ANOVA, is a statistical method used to compare means when there are three or more groups. When there is only one independent variable in the ANOVA test, it is known as a one-way ANOVA. The null hypothesis assumes that all means are equal and uses the F distribution for testing (Wahid *et al.*, 2018). In this study, the independent variable is solely based on the "slope" parameter. The ANOVA technique was applied to assess the relationship between slope and various proposed skid trails. The objective of this research is to explore the correlation between slope and the suggested skid trails.

As for the operation of drones, images captured using drones will be needed for mapping, 3D modelling and integrating with GIS information to accomplish the second objective. Mapping and 3D modelling for skid trails are needed for FMU to plan whether the existing skid trails are relevant to be used (in terms of cost-benefit, time and manpower) or if there is a necessity for proposed new trails for extracting harvestable trees from stand sites to roadside landings.

3. Expected Outcome

The information gathered and established from this study are needed to analyse whether the existing skid trails are suitable for the re-entry of blocks and whether the impact of re-entry of skid trails can be assessed by using the slope parameter. Thus, skid trail gradient compliance towards the RIL Plan can be evaluated. Alternative skid trail routes can be generated through modelling to compare the optimal length of the route with high accessibility to harvestable trees. This result is important to justify the accessibility to harvestable or marketable trees and the length of the route of the skid trail from the stand site to the roadside landing.

4. Conclusions

The additional scientific finding on the application of drones to identify skid trails in the logged-over forests would help FMU in the planning and practising of the RIL Guideline. Besides that, this study is also important to create innovative approaches using drone technology in the forest industry. This is also in line with the Sarawak Forest Policy Statement which emphasises good management of forest areas within the Permanent Forest Estate (PFE). In addition, the application of UAV technology (drones) in creating innovative approaches in the forest industry is also in line with "Thrust 9" of the prevailing Sarawak Forest Policy which is "Technology Application in Forestry Management". The results from this study are not confined to local use, the findings can be further applied to other tropical regions particularly in areas where sustainable forest management practices are carried out.

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