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IMPLEMENTATION OF UAV LIDAR FOR SURVEYING PAVEMENT CONDITIONS COVERED BY DIFFERENT VEGETATION DENSITIES

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Abstract

This study examines the effectiveness of UAV LiDAR technology in surveying road pavement conditions in areas with varying vegetation densities, a significant challenge in tropical environments like Indonesia. High vegetation density along roadsides obscures damage detection, limiting UAV LiDAR's application. This research was conducted along a 200-meter road segment in Bandung, West Java, Indonesia, with areas classified by vegetation density into sparse (0-35%) and dense (>70%) categories. UAV LiDAR captured data efficiently in sparse vegetation zones, but its effectiveness decreased in dense coverage areas, missing critical damage indicators. To address these limitations, we also employed a SLAM Scanner, which, unlike UAV LiDAR, operates flexibly under dense vegetation. The SLAM Scanner results closely aligned with manual survey data, achieving a 94.61% similarity, compared to 86.52% for UAV LiDAR. Although UAV LiDAR reduced survey time and costs, SLAM Scanner proved more reliable for dense vegetation zones, achieving higher detection rates for various road damages. This study highlights SLAM Scanner's potential as a viable alternative to UAV LiDAR for road surveys in densely vegetated areas and suggests further exploration of sensor fusion and optimized flight paths to enhance UAV LiDAR's applicability in tropical terrains.

Keywords: Road condition survey, SLAM scanner, UAV LiDAR, Vegetation density.

1. Introduction

Road pavement surveys are essential for assessing pavement conditions and identifying indicators of road quality degradation, such as structural and functional damages [1]. While these surveys are typically conducted periodically, those in hilly or mountainous areas are more resource-intensive due to challenging topography, with 45.77% of Indonesian villages located in such regions [2]. Utilizing UAV (Unmanned Aerial Vehicle) technology offers a solution to these challenges, reducing survey costs and time while providing high-resolution data with centimeter-level accuracy [2-7]. UAVs enable safer and more efficient data collection, making them a valuable tool for road maintenance [8-10].

Tamansari Road in Bandung City, West Java, Indonesia, has dense roadside vegetation with a density of 83.57%, making the road pavement difficult to observe using UAVs. Although UAV technology is increasingly used for road surveys, it has limitations in detecting damage in areas with high vegetation density [11, 12], as shown in Fig. 1. Vegetation along roadsides is classified into Open (0%), Sparse (<35%), Moderate (35-70%), and Dense (>70%) categories [13].

Fig. 1. Survey results using UAV covered by trees and vehicles.

Light Detection and Ranging (LiDAR) technology offers a solution for assessing road conditions in areas covered by vegetation, using light rays to collect accurate positional data similar to radar or sonar [14, 15]. LiDAR is a remote sensing technology that uses light rays to collect position information about surrounding objects. It efficiently maps lanes in a single pass, producing high-accuracy data [16-18].

Previous research has shown that UAVs can reduce survey time and costs while increasing accuracy, although vegetation remains a challenge [10, 11, 19]. LiDAR's ability to penetrate tree cover makes it valuable in these situations. Studies by Li et al. [20] and Elamin and El-Rabbany [21] demonstrated that UAV LiDAR can detect road damage with over 90% accuracy at lower flight altitudes, while Knoll [22] successfully mapped terrain beneath dense vegetation using this technology.

This research aims to apply UAV LiDAR technology as both a tool and a visual medium for assessing road pavement conditions, with the goal of accelerating road condition evaluations and improving the management of road damage.

2. Methods

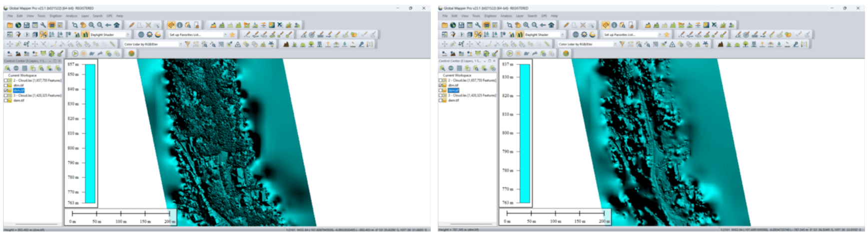
The research method involved a preliminary survey of Tamansari Road, a 200-meter long, 7-meter-wide primary collector road. Pavement damage, mainly patching and edge cracks, was observed, and vegetation density was classified (Fig. 2). A manual road condition survey followed, using SDI and PCI methods, with sample units divided into 50-meter sections for PCI and 100-meter segments for SDI [23, 24].

Fig. 2. Vegetation density classification on Tamansari Road.

For the UAV LiDAR survey, tools like the DJI Matrice 300 RTK UAV, Zenmuse L1 LiDAR payload, and DRTK 2 GPS were used (Fig. 3). Flight missions were conducted at 70 meters (45° angle) and 100 meters (90° angle) at 3 m/s. Collected point cloud data were processed into a Digital Terrain Model (DTM), excluding non-terrain features, and a Digital Surface Model (DSM), which includes all surface details (Fig. 4).

(a) (b)

Fig. 3. UAV LiDAR survey equipment: (a) DJI Matrice 300 RTK UAV and DJI Zenmuse L1 LiDAR Payload, (b) DJI DRTK 2 Geodetic GPS.



(a) **(b)**

Fig. 4. Processing data (a) DSM, (b) DTM.

3. Results and Discussion

UAV LiDAR proved unsuitable for surveying roads covered by vegetation, as it could not detect roads obscured by trees (Fig. 5). To address this, a more flexible alternative, the Simultaneous Localization and Mapping (SLAM) scanner, was used. SLAM scanners are portable, handheld LiDAR devices that can operate effectively under vegetation and are already utilized in fields like mining and bridge digitization [25-27], showing significant potential for road damage assessment.

Fig. 5. The road beneath the vegetation was not captured by UAV LiDAR between STA 0+100 and STA 0+150.

3.1. Road condition survey using SLAM scanner

The tool used is the STONEX X 70GO (see Fig. 6). This device is a LiDAR with a more flexible operation because it can be manually adjusted according to needs. The STONEX SLAM Scanner has a scanning capability of 200,000 points per second and is equipped with a 12-megapixel camera.

Fig. 6. STONEX X 70GO.

Before starting the survey, the SLAM Scanner needs to be calibrated. Position the device facing a wall and wait until a notification indicates that the SLAM Scanner is ready for use. Data collection with the SLAM scanner is performed by walking slowly through the survey area, holding the tool steadily in front to ensure optimal data capture. Slower movement enhances the scanner's ability to gather comprehensive point cloud data. Data collection process using SLAM scanner can be seen in Fig. 7.

Fig. 7. Data collection process using SLAM scanner.

After data collection, processing involves registration, filtering, and meshing stages using software like GOpost and Microstation to refine the data for visualization. Figure 8 shows the results of the registration.

Fig. 8. Display of registration results.

3.2. Identification of UAV LiDAR and SLAM scanner surveys

Processed data from the UAV LiDAR and SLAM Scanner surveys were used to identify road damage. UAV LiDAR struggles with detecting damage in dense vegetation but can identify features in areas with sparse cover, as shown in Fig. 9.

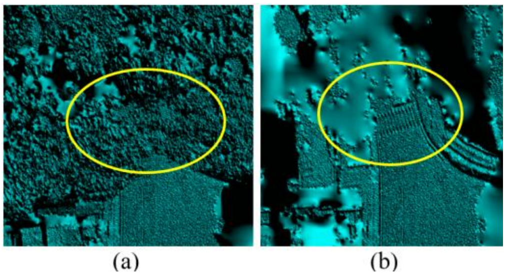


Fig. 9. UAV LiDAR's capability to penetrate sparse vegetation, (a) Before filtering, (b) After filtering.

On Tamansari Road, only medium to high severity patching and edge cracks were detected, while other minor damages were not captured by either tool. SLAM Scanner successfully identified patching damage that UAV LiDAR missed due to vegetation obstructions (Figs. 10 and 11).

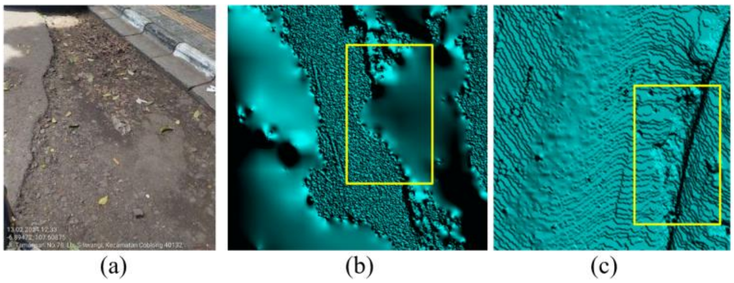


Fig. 10. Captured results of edge crack damage, (a) Field condition, (b) UAV LiDAR, (c) SLAM scanner.

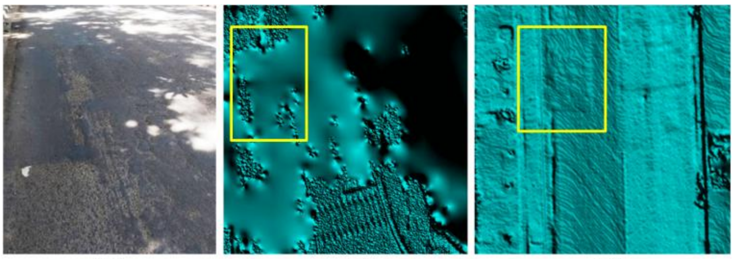


Fig. 11. Captured results of patching damage,
(a) Field condition, (b) UAV LiDAR, (c) SLAM scanner.

Overall, UAV LiDAR demonstrates high effectiveness in detecting features within areas of sparse vegetation. However, its ability to identify damage is significantly hindered in regions characterized by dense vegetation cover.

3.3. Comparison of UAV LiDAR and SLAM scanner

After identifying road damage, the dimensions were recorded, and PCI and SDI values were calculated. Table 1 shows a comparison of the survey results from the three tools used.

Table 1. Comparison of manual PCI, UAV LiDAR, and SLAM scanner.

No.	STA		Sample Unit	Manual		UAV LiDAR		SLAM Scanner	
				PCI Score	PCI Class	PCI Score	PCI Class	PCI Score	PCI Class
1	0+000	0+050	1	93	Very Good	100	Very Good	98	Very Good
			8	85	Good	100	Very Good	88	Very Good
2	0+050	0+100	2	78	Good	100	Very Good	82	Good
			7	100	Very Good	100	Very Good	100	Very Good
3	0+100	0+150	3	100	Very Good	100	Very Good	100	Very Good
			6	95	Very Good	100	Very Good	97	Very Good
4	0+150	0+200	4	80	Good	100	Very Good	83	Good
			5	74	Good	100	Very Good	95	Very Good
Average PCI					88.1		100.0		92.9
					Very Good		Very Good		Very Good
Comparison						Manual vs UAV LiDAR	86.52%	Manual vs SLAM Scanner	94.61%

The results showed that SLAM Scanner data closely matched manual survey results with a 94.61% similarity, while UAV LiDAR, averaging a PCI of 100, failed to detect damage due to dense vegetation coverage.

For SDI values in Table 2, the SLAM Scanner again performed better, while UAV LiDAR registered no damage. Although UAV LiDAR is faster, covering 1.5 km in 15 minutes compared to the SLAM Scanner's 200 meters at the same time, its effectiveness is limited in densely vegetated areas.

Table 2. Comparison of manual SDI, UAV LiDAR, and SLAM scanner.

No.	STA		Manual		UAV LiDAR		SLAM Scanner	
			SDI Score	SDI Class	SDI Score	SDI Class	SDI Score	SDI Class
1	0+000	0+100	20	Good	0	None	15	Good
2	0+100	0+200	20	Good	0	None	15	Good

3.4. Factors affecting survey results

Several factors affect the accuracy of UAV LiDAR and SLAM Scanner surveys. For UAV LiDAR, using oblique mode (zigzag flight pattern) can enhance data density [28] and terrain-follow mode optimizes altitude for better detail. For SLAM Scanner, slow and steady data acquisition improves accuracy, and conducting surveys during off-peak hours reduces the likelihood of road sections being obscured by traffic [26].

4. Conclusions

This study demonstrates that while UAV LiDAR is a valuable tool for road condition surveys in sparsely vegetated areas, its effectiveness is significantly reduced under dense vegetation, where critical road damage indicators may be missed. In contrast, the SLAM Scanner, although slower and more labour-intensive, offers a reliable alternative for densely vegetated regions, closely aligning with manual survey results and achieving a higher detection accuracy for various damage types. The findings suggest that combining UAV LiDAR for open or sparsely vegetated zones with SLAM Scanner technology for densely covered areas can provide a comprehensive approach to pavement assessment in tropical environments. Future research should explore enhancements to UAV LiDAR capabilities, including optimized flight paths and sensor fusion, to improve data accuracy and applicability in dense vegetation contexts. These adaptations have the potential to expand the utility of UAV technology in complex terrains, making it a more versatile tool for road infrastructure management in diverse environmental conditions.

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