AUTOMATIC RETRIEVAL OF RAILWAY MASTS TILT ANGLE FROM MOBILE LASER SCANNING DATA

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ABSTRACT: Mast plays an essential role in supporting objects, i.e., catenary, droppers, etc., in the railway electrification system. The condition of the tilt railway mast can influence the entire railway transportation safety. Therefore, the tilt angle of the railway masts needs to be retrieved to prevent damage. This study proposed an automatic method to retrieve the tilt angle masts by using Mobile Laser Scanning (MLS) point clouds data. Forward, the automatic method was tested into two-track locations, which in New Taipei city and Yilan county, in the north of Taiwan, respectively, had been used in our automatic detection method. The data was acquired two times, on July and October 2019. There were two main steps to retrieve the tilt condition of the railway masts. Firstly, point clouds were clustered by using Euclidean Distance Clustering and detected the masts by setting parameters. Secondly, the tilt angle of the mast was obtained by Principal Component Analysis (PCA) and was calculated based on vector-based. The result showed that 90% and 89% masts were detected in New Taipei City, respectively in the first and second acquisitions. In Yilan county, 82% masts were successfully detected. The RMSE of the tilt angle estimation result was 1.2° and 1.6°, respectively in New Taipei City and Yilan county.

KEY WORDS: Masts Detection, Tilt Angle, Mobile Laser Scanning (MLS)

1. INTRODUCTION

Rail transportation is a well-known mode of land transportation due to its low cost and abillity to move accross in the long distance. Taiwan has used this mode of transportation to convey over than 232 million passangers (Ministry of Transportation and Communication, 2018). In 2020, Taiwan Railway Adminstration (TRA) has completed an electrification system along the railway (Kelvin, 2020). The conversion of diesel to electric power aims to increase the train speed and reduce carbon emission from the diesel train engine (Railway Bereau, 2019). In the electrification system, mast plays an important role to support various component of overhead line equipment (OLE), including massanger and contact wires. The trains receive the electricity power from the contact wires through the pantograph. If the mast experience tilted, there is posibility contact loss that can be dangerous for railway transportation and the passenger as well. Therefore, the tilt angle of railway masts need to be observed.

In order to observe the mast, temporal observation are required. However, retrieving field survey data on railway is hazardous to employees. By using Mobile Laser Scanning, the data retrieval can be performed safely and increase the temporal periods. Thus, this research proposes to retrieve the tilt angle automatically from the MLS point clouds data. Before obtaining the angle, we need to detect the mast. Several researchers has developed methods to detect the mast automatically. Landa and Ondroušek (2016) developed a method for finding poles using euclidean clustering by dividing the data into horizontal slices and structuring the cluster using a directed vector. Euclidean clustering was also utilized to detect the mast and then categorize the masts into various classes Yan et al. (2017). Yokoyama et al. (2011) used k-nearest neighbors clustering to eliminate non-mast object, and then the result was regenerated using Laplacian smoothing and Principal Component Analysis.

Considering the ability of euclidean clustering that can cluster rapidly and efficiently on huge amount data, this research applied its method. In order to obtain the tilt angle formed between first and second acquisition, vector-based calculation are used. With the tilt angle, we can notice the mast conditions, Therefore, this research also proposed the automatic method to retrieve the tilt angle of the mast from Mobile Laser Scanning (MLS) data.

2. METHODOLOGY AND STUDY DATA

2.1 Study area and Dataset

The study area are located in Northern Taiwan. The first location, known as track A, is located in New Taipei City and has a total length of approximately 7 km. MLS data is collected in track A from Sandiaoling station, continues through Mudan station, and ends at Shuangxi station. Track B is the second location which is located in Yilan County. Data collection in track B begins at Daxi station, continues to Dali station, and concludes at Shincheng station. Track B is approximately 7 km in total. Each track is acquired twice, in July and October of 2019. Figure 1 shows the study area of this research.

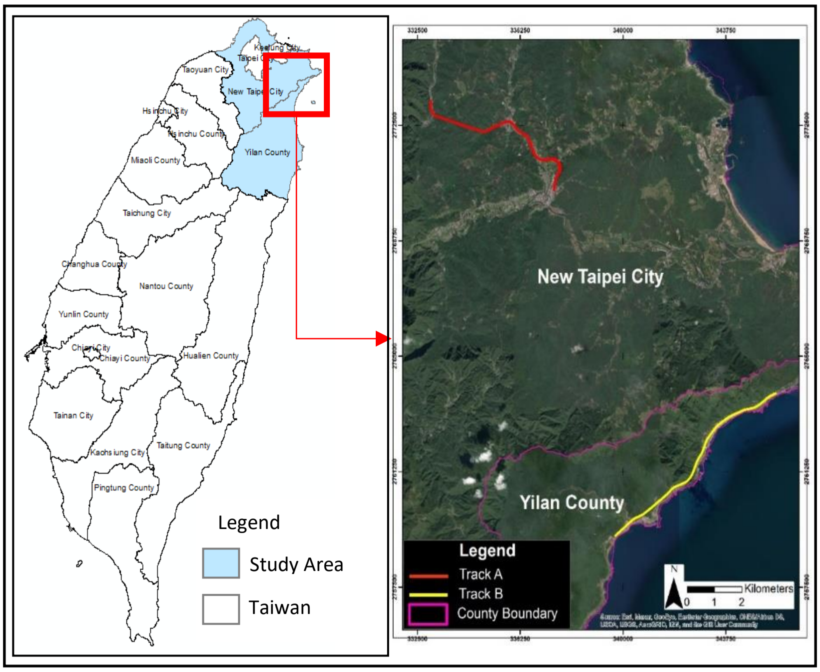


Figure 1 Study Area: Track A and Track B

To process the method, three datasets were used such as MLS point clouds, GPS trajectory and digital elevation model (DEM). MLS point clouds were separated into data subsets with unique identifiers. Track A had 76 data subsets, whereas track B had 75 data subsets. DEM was generated by TerraScn software after classifying MLS point clouds data into ground and non-ground. The company was in charge of developing the DEM data. Furthermore, in order to reach a stable location and orientation of the vehicle, the trajectory data was collected by calculating the coordinates X, Y and Z of all points measured.

In the field of study, three types of masts, track A and track B, can be found. The first type is circular with a concrete structure. The other types are truss and h beam. The three type of masts are shown in Figure 2.

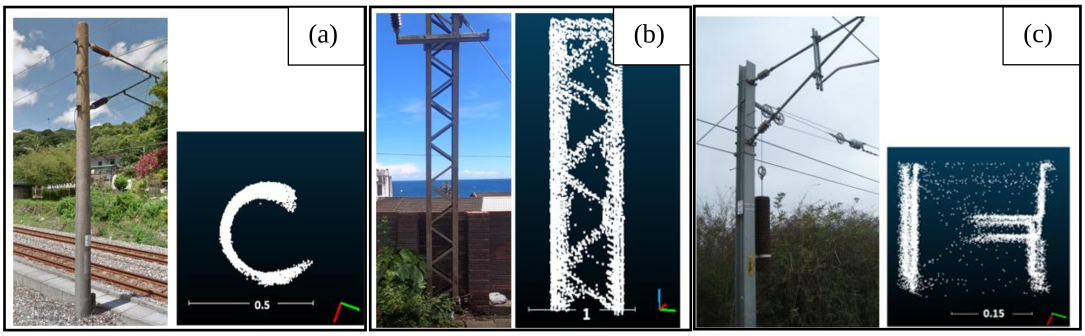


Figure 2 Type of Masts (a) Side and top view of Circular, (b) Side view of Truss, (c) Side and top view of H beam

2.2 Method

This research proposed an automatic method for retrieving the railway mast tilt angle, which must be monitored. As illustrated in Figure 3, the procedures consist of three major components: pre-processing, mast detection, and tilt angle estimation.

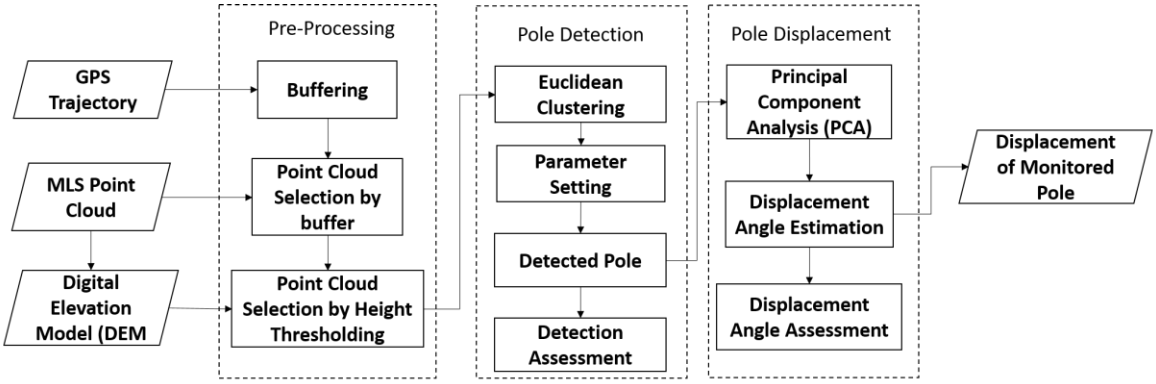


Figure 3 Flowchart

2.2.1 Pre-Processing

In order to reduce unused points and remove the connection between the masts, MLS point clouds are selected by using buffer and height thresholding. The GPS trajectory data used to select the point clouds by buffer area is a line with X, Y, and Z coordinates as the center of the buffer area. To generate the buffer area, ArcGIS 10.7.1 is used (Esri Inc.). The buffer size is determined by considering the existance of the railway lanes types. In this research, the railway lanes are double track and quadruple track. Thus, the buffer size is following the quadruple tracks which is 13 m in both tracks, track A and track B. The assumption is if we use the quadruple tracks size, the double tracks still can be covered. After buffering, the MLS point clouds that are outside the buffer area are deleted.

The height thresholding requires the Digital Elevation Model (DEM). Point clouds connected with the mast have to be removed since they are linked to the ground and cable points. The XY plane is filled with MLS point clouds (Tran & Taweep, 2020; Yan et al., 2017). Based on the precision of the DEM, the MLS point clouds are then split into 2D grids with an area of 0.3 x 0.3 meters, as illustrated in Figure 4. After constructing into XY plane, MLS point clouds that are within 2 meters to 4 meters of the ground are selected. The minimum thresholding value is considering the height of the fence and small bush around the mast. The maximum thresholding value is considering the distance between overhead line equipment (OLE) to the ground.

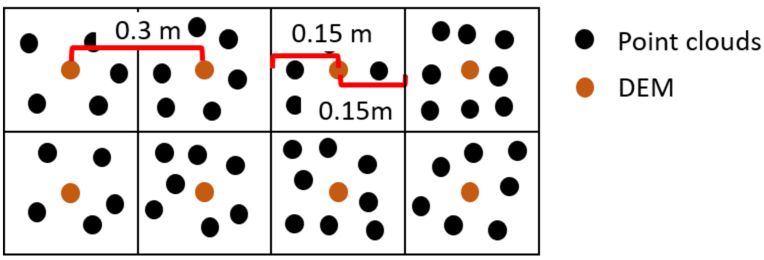


Figure 4 Illustration of XY plane.

2.2.2 Mast Detection

MLS point cloud need to be grouped into spesific clusters. Euclidean clustering is selected because its capacity to group huge data rapidly and efficiently. When the Euclidean distance between points is less than the minimum distance parameter, MLS point clouds are merged into same cluster. Otherwise, it generates new clusters. This research is used the minimum distance parameter about 0.1 m. To detect the masts, three size threshold are set based on Δx, Δy, and $\Delta \ell$. The size threshold of Δx and Δy is 1.3 m which considers the tensioning system attached to the mast. The size of $\Delta \ell$ is 1.6 m which considers the lamppost height so that is not detected as masts.

2.2.3 Principal Component Analysis

Detected masts are then calculated their directions. Principal component analysis (PCA) can provide the directions in the X, Y and Z axes. PCA is a statistical approach for multidimensional analysis that tries to reflect data variability (Stabilini et al., 2021; Wold et al., 1987). To obtain the principal component, eigenvector and eigenvalue are calculated. The eigenvector with the highest eigenvalue is the first principal component (PC1). This research shows that the first principal component is in Z axis which represent the mast positions. Figure 5 depicts the railway mast with its different directions.

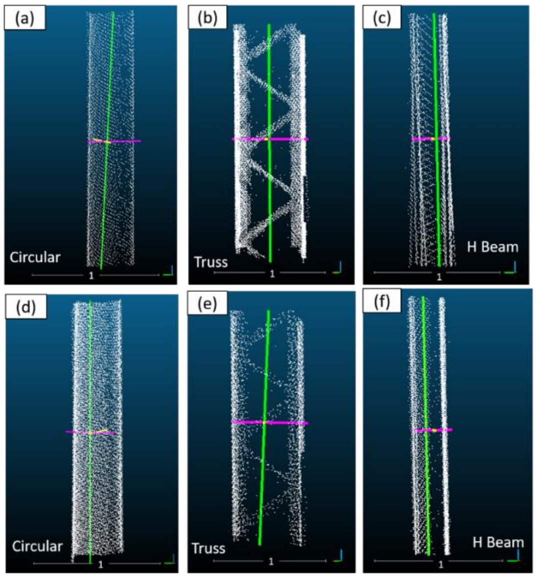


Figure 5 Side view of the direction: (a) (b) (c) Mast in the first acquisition, (d) (e) (f) Mast in the second acquisition.

2.2.4 Tilt Angle Estimation

The first principal component from the first and second acquisition is then calculated the angle by using vector-based equation. The angle formed from the first and second acquisition is used to find out how the mast experience change within three months period. The illustration of tilt mast angle is shown in Figure 6.

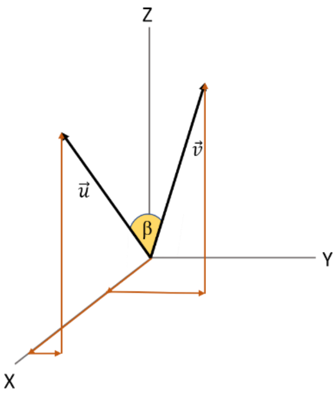


Figure 6 Illustration of tilt angle between two acquisitions.

$$\beta = \cos^{-1}\left(\frac{\vec{u}\,.\,\vec{v}}{|\vec{u}|\,.\,|\vec{v}|}\right) \qquad (1)$$

where:
β : tilt angle between two different acquisitions
$\vec{u}$: the first principal component of the mast in the first acquisition
$\vec{v}$: the first principal component of the mast in the second acquisition
$|\vec{u}|$: the vector length in the first acquisition
$|\vec{v}|$: the vector length in the second acquisition

2.2.5 AccuracyAssessment

An accuracy assessment is carried out to evaluate the performance of mast detection from the proposed method. The evaluation compares the masts successfully detected by the proposed method to the reference data. In each dataset, the reference data is manually detected by visual examination which the masts are the target element.

Table 1 Reference data of masts

	Circular	Truss	H Beam	Total
Track A	175	39	21	235
Track B	264	32	25	321

$$Recall = \frac{TP}{TP+FN} \quad (2)$$

$$Precision = \frac{TP}{TP+FP} \quad (3)$$

$$Omision\ error\ rate = \frac{FN}{TP+FN} \quad (4)$$

$$Commision\ error\ rate = \frac{FP}{TP+FP} \quad (5)$$

Where:
TP (True Positive) : the mast correctly detected compared to reference data.
FP (False Positive) : the total number of masts that are falsely identified as masts compared to reference data.
FN (False Negative) : the masts that not identified in proposed method.
Recall : indicates how many masts are properly recognized using proposed method.
Precision : defines the ratio of true positives to false positives produced by proposed method.
Omision error rate : the error from the number of undetected masts using proposed method.
Commission error rate : the error from the false positives produced by the proposed method.

The second assessment is to assess the tilt angle of the proposed method. The comparison tilt angle between manual method and proposed method is performed using Root Mean Square Error (RMSE), as shown in Equation (6).

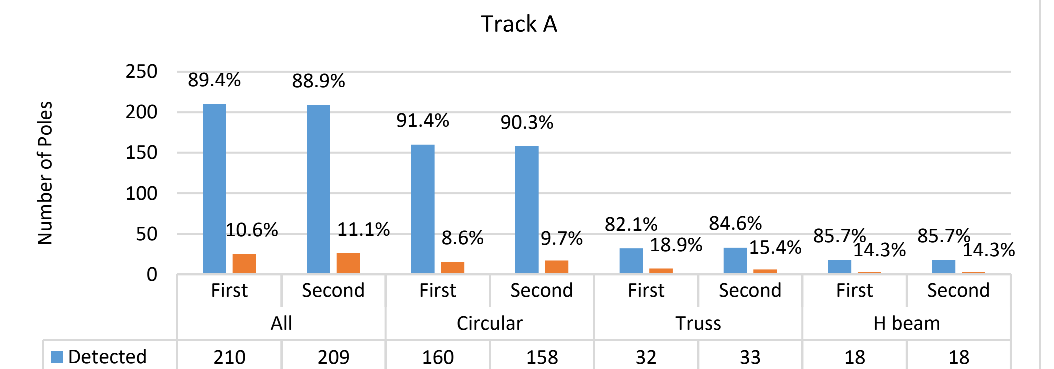
$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\beta_{proposed} - \beta_{manual})^2} \quad (6)$$

Where:
N : number of observed masts.
$\beta_{proposed}$: tilt angle estimation in proposed method.
β_{manual} : tilt angle estimation in manual method.

3. RESULT

3.1 Mast Detection Result

The proposed method successfully detects 210 of 235 masts in the first acquisition of track A. During the second acquisition of track A, 209 of the 235 masts are successfully detected. Using the same parameters, the number of detected masts in the first and second acquisition of track B is 264 out of 321 masts. Following the results, Figure 7 and Figure 8 show the complete result of detected masts in each different types including circular, truss and h beam.



	First (All)	Second (All)	First (Circular)	Second (Circular)	First (Truss)	Second (Truss)	First (H beam)	Second (H beam)
Detected	210	209	160	158	32	33	18	18
Undetected	25	26	15	17	7	6	3	3

Figure 7 Mast in track A

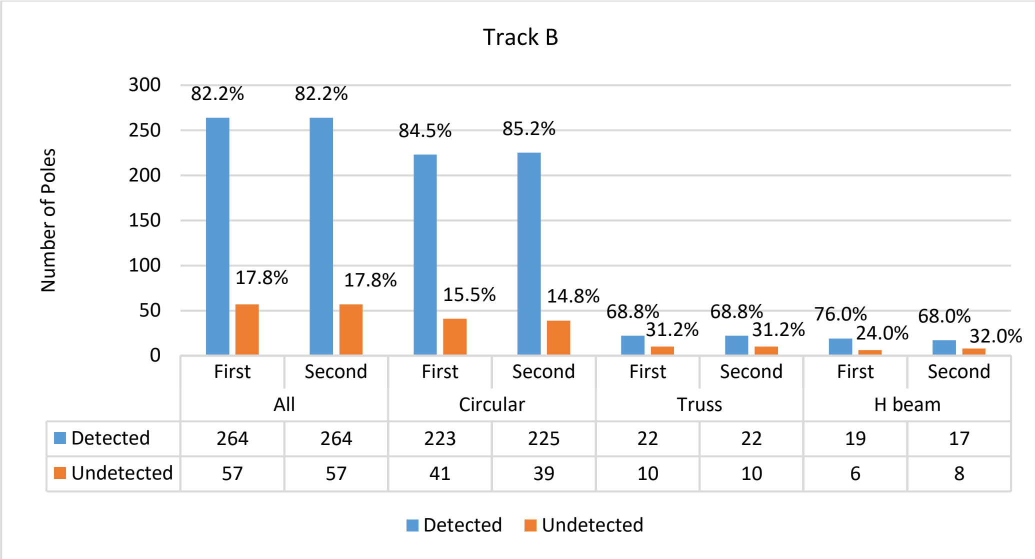


Figure 8 Masts in Track B.

The proposed method evaluation is shown in Table 2. According to Table 2, the recall values are indicated higher than precision values. The recall value is the number of masts accurately detected by the proposed method which is influenced by omission errors. Omission error indicates the number of masts that cannot be detected by the proposed method. Furthermore, a low precision value implies that erroneous masts have been recognized, which impacts the error of commission. Table 2 shows that the second acquisition of track B has the lowest precision value, which also has the highest value of commission errors rate. According to the findings of this study, the open-cut tunnel is detected as masts. In the second acquisition of track B, half of the false positives come from open-cut tunnels. The open-cut tunnel part are also discovered in the first acquisition of track A, accounting for more than 20% of true positives.

Furthermore, undetected masts are generated by object surrounding the masts, as illustrated in Figure **9**. On the other hand, we discover that some masts are removed during pre-processing. The reason is that we consider the size of the track up to quadruple track, but there is septuple track in track A, as shown in Figure 10. However, the number of detected masts exceed 80%.

Table 2 Evaluation of Masts Detection.

		Proposed Method	**Manual**	**TP**	**FN**	**FP**	**Commission**	**Omission**	**Recall**	**Precision**
Track A	1st	307	235	210	22	97	0.31	0.10	0.90	0.69
	2nd	277	235	209	20	68	0.26	0.11	0.89	0.74
Track B	1st	344	321	264	57	80	0.23	0.18	0.82	0.77
	2nd	406	321	264	57	142	0.35	0.18	0.82	0.65

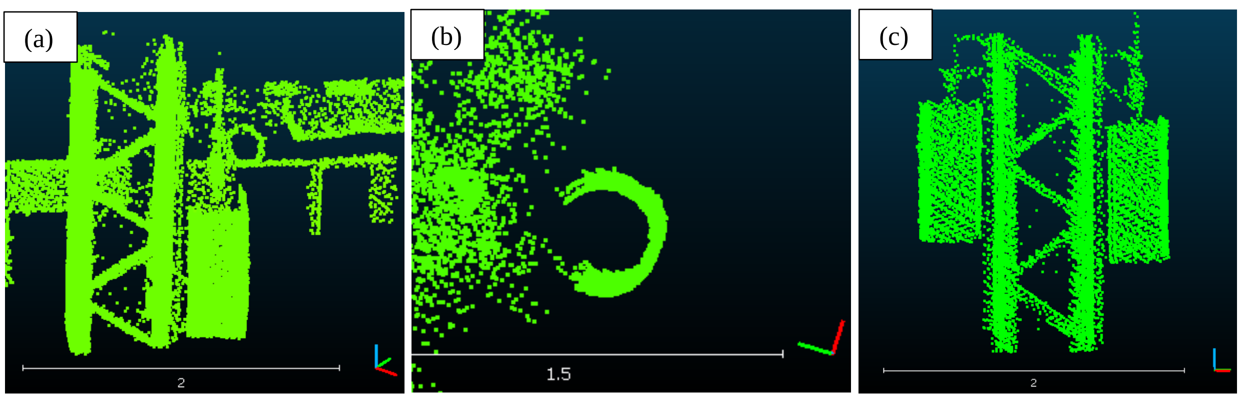


Figure 9 Example of the undetected masts caused by object surrounding the masts (a) side view, (b) top view, (c) side view.

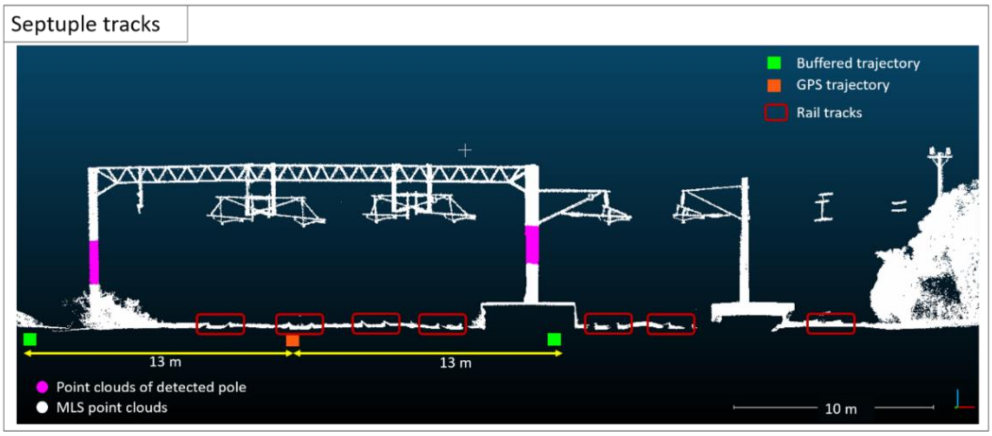


Figure 10 Septuple tracks in track A.

3.2 Tilt Angle Result

The tilt angle of the masts that are successfully detected in both acquisitions is then estimated using vector-based calculation. The assumption is that if the mast changes its position within the time periods, the angle is formed. Therefore, the masts that can be observed are detected in both acquisitions, as shown in Table 3. Following the calculation of the tilt angle, the proposed method is evaluated using reference data. The tilt angle result of the observed mast is shown in Figure 11 and Figure 12.

Table 3 The number of masts observed the tilt angle.

	Circular	Truss	H beam	Total
Track A	155	32	18	205
Track B	213	21	16	250

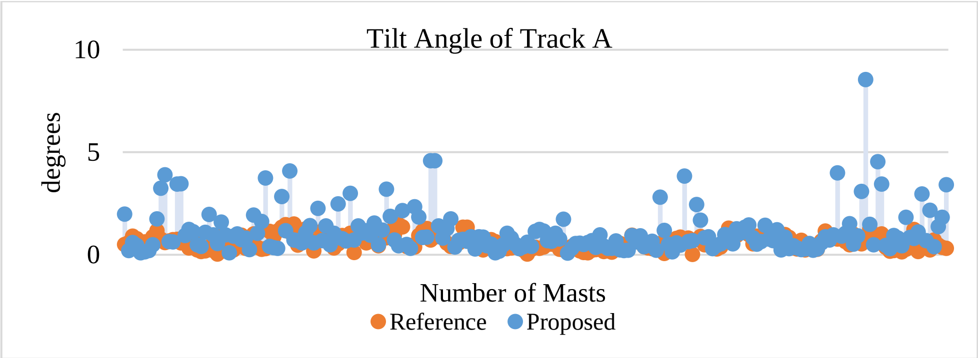


Figure 11 Tilt angle of track A

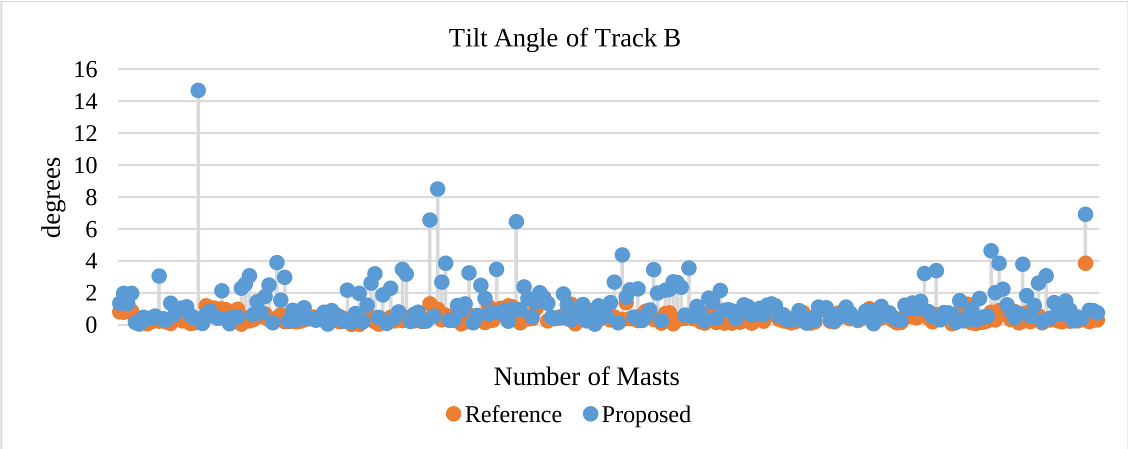


Figure 12 Tilt angle of track B

According to proposed method result, the lowest and highest angle values of track A are 0° and 8.5°, with an average angle value of 1.1°. The minimum and maximum values of angle estimation in track B are 0° and 14.7°, respectively, with an average angle of 1.3°. Figure 11 and Figure 12 also show the comparison of tilt angle between proposed method and reference. The mast that has high difference of angle is caused by the movement of tensioning system attached to the mast, as illistrated in Figure 13. Although there are several masts that have high difference angle, the RMSE of the proposed method to the reference is about 1.2° and 1.6°, respectively in track A and track B.

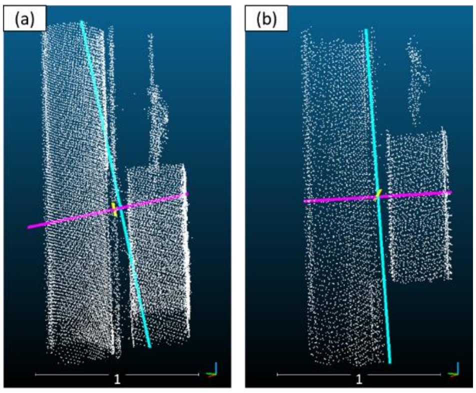


Figure 13 The movement of tensioning system attached to the mast.

4. CONCLUSION

The main purpose of this research is to retrieve the tilt angle of railway masts using MLS point clouds data. By obtaining the tilt angle, the condition of the masts can be monitored within interval periods. According to the result, the proposed methods show that the masts are in good conditions. This is can be proved by the average angle value of track A and track B. Both tracks have average angle value around 1° with RMSE errors about 1.2° and 1.6°. It also indicates that there is no change in the masts within three months interval. Further study is required to minimize the error angle estimate by removing the tensioning system attached to the masts. However, in this research, we provide a new perspective on the use of MLS point clouds for monitoring activities in a railway environment.

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