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To cite this article: G A Jessy Kartini *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **731** 012005

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Detection of Rail Geometry Irregularities Using Point Cloud Data from Terrestrial Laser Scanner (Study Case: Curve No. 106, Railroad between Cipatat-Tagogapu, Indonesia)

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Abstract. Geometry railroad irregularities can disrupt safety of the train that passes through it and the comfort of train users. In geometric inspection of rail, it requires reliable accuracy from survey data. Terrestrial Laser Scanner (TLS) offers the advantage of obtaining accurate measurements of objects or 3D model. This study aims to examine irregularities of widening gauge and cant rail in curve no. 106, railroad between Station Cipatat – Station Tagogapu based on Minister of Transportation Regulation No. 60 of 2012. The 3D rail model from the point cloud TLS can be used to extract changes of the gauge and height differences with the help of cross- sections. Extraction of gauge and height differences is carried out per 1 meter and given numbering. The results of both gauge and height differences are adjusted to the type of track from the results of the design of the curve, then compared with the value of the standard widening gauge and cant based on the Minister of Transportation Regulation No. 60 of 2012. The result extraction of the rail gauge in curve no. 106, shows the highest irregularities of widening gauge on the gauge number 24 with deviation value +0,017 m. The results of obtaining height differences rail extraction at curve no. 106, shows the highest irregularities of rail cant on the height differences number 15 and 16 with deviation value +0,022 m.

1. Introduction

Rail geometry is the shape and size of the rail, both in the elongated and transverse directions which include the gauge of the rail, slope, horizontal curve, vertical curve, cant, and track widening [1]. Rail geometry must be planned with reference to Minister of Transportation Regulation of the Republic of Indonesia number 60 of 2012 regarding Technical Requirements for Railroad. This planning must take into account safety, comfort, economic, and harmony with the environment [2].

Railroad maintenance includes checking the condition of the railroad and preparing maintenance programs. Checking the condition of the railroad is done as an initial measure to obtain data regarding the condition of a rail. Good geometry conditions of railroads are indispensable for the safety and comfort of train travel [3]. The existence of rail geometry irregularities can disrupt the security and safety of trains that pass through it and interfere with the convenience of train users. Therefore, a study of rail geometry irregularities is needed to ensure the safety of train users and property.

Terrestrial Laser Scanner (TLS) technology offers the advantage of obtaining accurate 3-dimensional (3D) object measurements around the railroad tracks in a short operational time [4]. In addition, the results of rail extraction from TLS point cloud data can be used to determine the geometry features of rail alignment (straight lines, vertical or horizontal curves,



transitional curves, cant, rail gauge, rail widening) and elongated profiles (slope) [5].

The focus of this research is to study the irregularities of geometric features (horizontal alignment), namely cant and widening of the rail in one of the curve in railroad between Cipatat - Tagogapu using point cloud data based on TLS survey results. This railroad geometry irregularities study refers to the Regulation of the Minister of Transportation No. 60 of 2012 concerning Technical Requirements for the Railroad.

2. Methodology Research

2.1. Location

The location used in this study is in the curve No. 106 railroad between Cipatat - Tagogapu, West Java Province, Indonesia. The track length of the location under study ± 120 meters. Based on its geographical position, the research location is between $6^{\circ}48'37''$ - $6^{\circ}48'38''$ South Latitude and $107^{\circ}27'46''$ - $107^{\circ}27'50''$ East Longitude. Detailed location of the study is shown in figure 1.



Figure 1. Location study.

2.2. Methodology

The methodology used in this study includes planning and field data collection, TLS data processing, model identification, determination of rail widening and cant, results and discussion. The stage diagram of the work in this study can be seen in figure 3.

2.3. Planning and Field Data Collection

The initial stage is the planning of control points and traverse points around the study site. The planned control points are 2 points namely P001 and P002, while the planned traverse points are 10 points, among others, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10 (figure 2).



Figure 2. Control points and traverse points.

The next stage is field data retrieval. GPS observations are made to obtain the coordinates of the control points and ETS is done to obtain the coordinates of the traverse points. GPS and ETS data are processed and then used as a reference for TLS scanning. TLS scanning was performed using Topcon GLS-2000 with a scan resolution of 12.5 mm at distance 10 m.

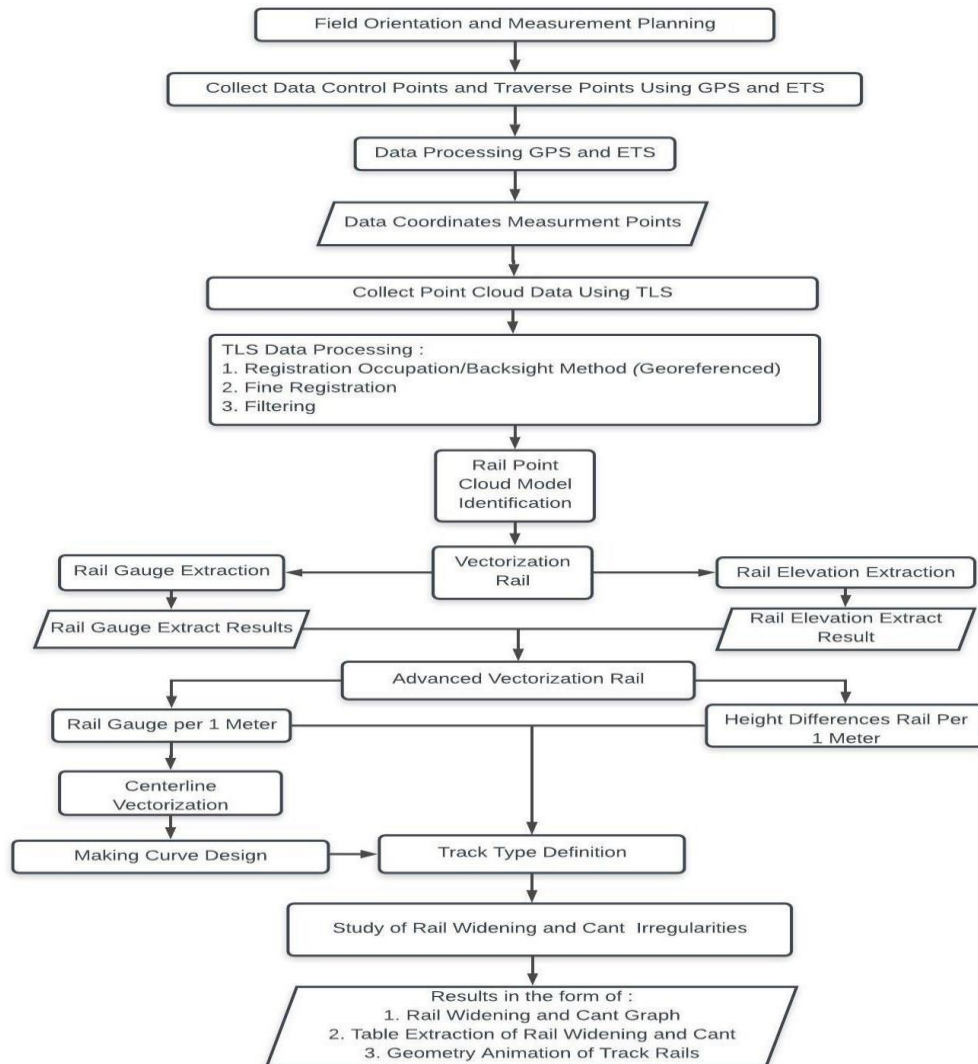


Figure 3. Research Methodology

2.4. TLS Data Processing

TLS processing is divided into 3 stages, namely registration, georeferencing, and filtering. The registration method used is occupation / backsight and additional fine registration in order to obtain a better RMS registration. The use of the occupation / backsight method produces real coordinates so that the point cloud data has been georeferenced automatically. The results of occupation / backsight registration and fine registration are shown in Table 3.

Table 1. Result of Occupation/back-sight dan fine registration.

Reference	Registration	RMS (Meter)
P001	T1	0.009
T1	T2	0.009
T2	T4	0.013
T4	T5	0.008
T5	T6	0.007
T6	T7	0.008
T7	T8	0.008
T8	T9	0.008
T9	T10	0.011
RMS Mean		0.009

The last step is filtering. Filtering is done to remove points that are not needed outside the rail track. Filtering is done so that the point cloud is not too large so it does not burden the next process. This process is not carried out to remove noise in the railroad tracks, such as grass or rocks. Removing noise that is close to the rail can cause the rail points to disappear.

2.5. Point Cloud Rail Model Identification

The results of the rail model formed by point cloud show error points with varied errors. The distribution point cloud to form rail model should form a planar object on the linear part. Differences in the rail model registration results and the rail model that should be (planar), cause the extraction results of both the gauge and elevation of the rail to contain errors. In order not to increase the error due to the varying position of the rail gauge vector and rail elevation, the R33 rail profile model needs to be adjusted to the point cloud rail model. This rail profile model is overlaid with the rail point cloud model, so the vectorization points are determined based on the rail profile model. This rail profile model was made in the Bentley Inroads software with reference to drawings based on rail profile size. The overlay location of the point cloud model with the rail profile model needs to be determined so that the model is overlaid accurately. The locations chosen to overlay the point cloud model with the rail profile model are the logical points forming a rail model. The selection of points at this location is interpretive during the railroad vectorization and rail elevation processes. Overlaying of the model of the rail profile is also carried out at locations where the top surface point of the rail head is not detected. The overlay of the rail profile model and the point cloud rail model are shown in figure 4.



Figure 4. Overlaid rail profile model on point cloud rail

In identifying rail models for vectorization, it is also necessary to consider the thickness of the cross section. The determination of cross section affects the accuracy of the rail point cloud model. The thickness of the cross section depends on the curvature of the track and the density of the rail point cloud. At a position where low density, large cross section thickness will represent a better model, in contrast to high density. In a position where the curvature is large, a small cross section thickness will represent a better model, in contrast to high density [6]. The thickness of the cross section used in this study is in the range of 5 mm to 3 cm. Cross sections in each rail model are tried over and over in a predetermined range to get a good interpretation. The relationship of cross section thickness on the point cloud rail is shown in figure 5.

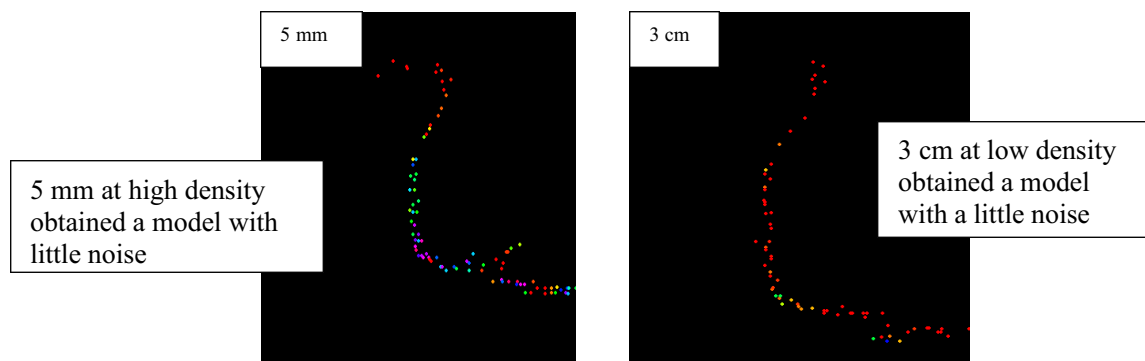


Figure 5. Relationship of cross section thickness on point cloud rail.

2.6. Determination of Rail Widening and Rail Cant

The initial stage in the process of determining the horizontal alignment feature is extracting the rail gauge and rail elevation. The process is by vectorizing the gauge and elevation of the rail at the point cloud of the inner rail and outer rail. Vectorization rail gauges and rail elevations are done under different conditions. The gauge of the rail is done 0-14 mm below the top surface of the rail according to the provisions of the technical requirements of the railroad track. Whereas for rail elevation, vectorization is done on the top surface of the rail. Vectorization is done with the help of using the cross section display of the rails, the points that are crossed by the vectorization line are determined manually and adjusted to the point cloud rail based on the stipulated conditions. Furthermore, the gauge and elevation rail results are extracted using the extract rail gauge feature on the VR-Mesh Survey software. The results of gauge extraction and elevation are used for advanced vectorization to correct previous vectorization points. The results of extraction rail gauge and elevation then re-vectorized on the Bentley Descartes V8i software. The rail profile model is overlaid on the rail point cloud model. This rail profile model is used as a reference to correct the elevation point and gauge point of the rail. Cant rail are calculated based on the differences between two rail elevation and gauge rail calculated based on straight line from two points between two rail. Next, the middle point coordinates of the rail gauge line are used to vectorize the centerline rail. Centerline rails are used for creating track geometry animations. Next step, the curve design is made using the parameters of the transitional curve length, curve radius, and the two initial and final existing centerline points. This curve is made using the spiral-curve-spiral feature in the Bentley Power Inroads software. The vectorization lines of the gauge and elevation of the rails are compared to the curved design so that a type of track definition is obtained for each number of gauge and different rail heights. The type of track definition is line, transitional curve and full circle curve. Rail gauge and rail height differences are numbered sequentially from number 1, 2, 3, and so on from the direction of Cipatat towards Tagogapu.

3. Results and Discussion

The results obtained from this study are graphs and tables of widening and cant of the extracted rails. The widening and elevation graphs of the rails are shown in Figs. 6 and 7.

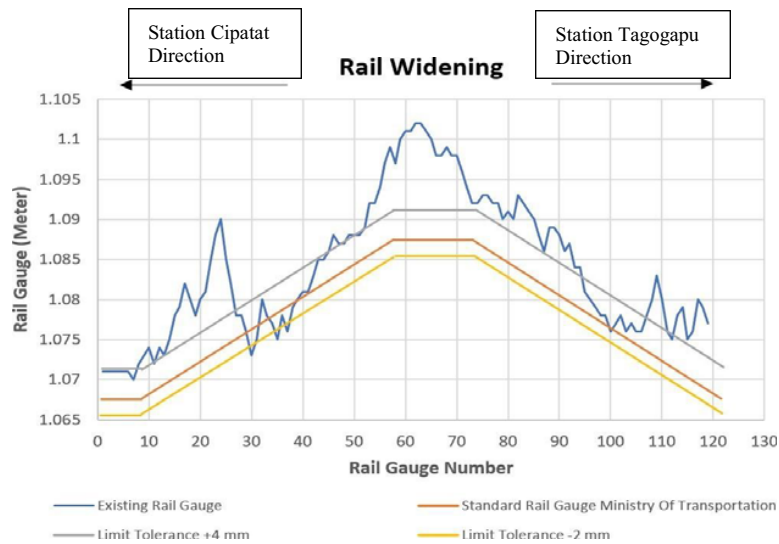


Figure 6. Rail widening chart.

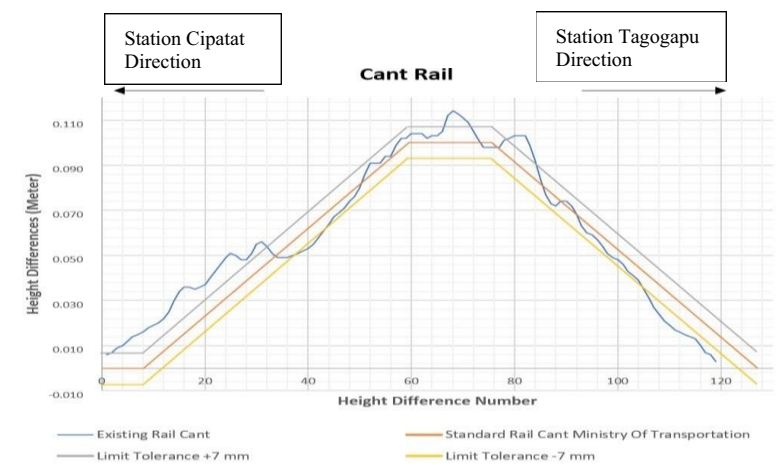


Figure 7. Cant rail chart.

3.1. 3D Rail Model form Point Cloud

Point cloud on the top surface of the rail head results in poor distribution of points. Many of the points on the surface of the head rail are not detected properly by TLS, so that some point cloud rail models are not formed perfectly. According to [7] the surface of a shiny object is usually difficult to record. A shiny object depends on the material or layers on the object itself. This may occur in steel material or layers lining the top surface of the rail head which caused by direct reflection of sunlight so that the top surface of the rails shiny. However, this can also be influenced by the scanner's inability to obtain rail data, especially the top surface of the rail head, so more in-depth research is needed for this case. In addition, the undetected surface of the rail head is also affected by the increasing distance of the object to the scanner. The distribution of the top surface points of the rail head that is close to the scanning station has

more points than points far from the station. Vectorization for rail elevation is done by overlaying the rail profile model on the rail point cloud model. Vectorization lines at undetected points are determined based on the top surface of the rail head profile model.

At some stations, the scanning position is focused on obtaining point cloud data on the top surface of the rail head and a small part of the side rail head, especially at locations far from the two scanning stations. However, based on previous studies of the top rail head surface model where the distribution of the top surface points of the rail head is poor, causing the distribution of point clouds in the rail head to disappear entirely at certain locations. These locations are between stations T5-T6 with a length of ± 6 meters and between stations T7-T8 with a length of ± 4 meters. In addition, in the scanning area between P001-T1 stations, the rail conditions are below the ground or vegetation so that the model is not visible with a length of approximately ± 2 meters. The measurement values on the gauge and height differences of this location are ignored and marked in red in the widening and elevating rail table attachments.

The 3D rail model of point cloud registration results shows an error points. Bias in rail models especially rail heads can cause errors in the gauge and height differences measurement. Error points are caused by many error factors including GPS observations, polygon measurements, TLS errors, noise, cross section thickness and others. The biggest factor of error is the coordinates on the Z axis. This is indicated in the shape of the top surface of the rail head that has more error points than other rail sections. This error is caused by the accumulation of GPS, ETS, and TLS errors. Although fine registration has been done to obtain better registration results, the maximum RMS results obtained are only in the range of 7 mm to 1.3 cm. In this biased rail model, the solution for determining the point of vectorization is by the overlay of the point cloud rail model with the rail profile model.

3.2. *Rail Widening Irregularities*

The study of railroad irregularities is carried out based on track definition and widening of the PM standard rail. No. 60 of 2012 in accordance with figure 6. The definition of the railroad track is divided into three types, namely straight track, transition curves and full circle curves. Curved no. 106 on the Cipatat - Tagogapu railroad has a radius of 150 m. Irregularities are examined based on visualization of changes in both the increase and decrease in the widening of the rail from the results of the graph and the value of the deviation. The gauge of the railroad at full circle curve for $100 < R < 350$ radius of curve is 20 mm, so the gauge of the track at the full circle curved is $1.067 \text{ m} + 20 \text{ mm} = 1.087 \text{ m}$. Widening in a straight line is 0 or no widening. In the transitional curve widening value is varies, increase gradually before the full circle curve and decreases after the full circle curve in accordance with the direction of depiction on the graph. The deviation tolerance in the railroad between Cipatat-Tagogapu is +4 mm and -2 mm.

The results of the study of rail widening irregularities in curve no. 106 shows deviations exceeding the tolerance limits of +4 mm and -2 mm in rail gauge numbers 8, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 30, 35, 37, 46, 47, 48, 49, 52, 53, 54, 55, 56, 57, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 80, 81, 82, 83, 89, 90, 91, 92, 108, 109, 110, 113, 114, 116, 117, 119, and 120. The biggest deviation occurs in the rail width number 24 with a value of deviations + 0.017 m.

3.3. *Rail Cant Irregularities*

Cant rail irregularities study is based on the track definition and standard rail cant Minister of Transportation Regulation No. 60 of 2012 according to the graph in figure 7. According to regulation of the Minister of Transportation of the Republic of Indonesia number 32 year 2011 regarding Railways Maintenance Standards and Procedures, if the existing height differences value > 7 mm compared with theoretical height differences value, then the railroad must be repaired. This 7 mm limit is used as a reference for rail height deviation tolerance. Value of the cant in full circle curve no. 106 is 0.100 m or 100 mm and in straight track the height

differences is 0 which means there is no cant. The rail cant in the transition curvature varies and is elevated gradually in the transitional curve before the full circle curve then decrease gradually in the transitional curve after the full circle curve.

The results of the study of rail cant irregularities in curve no. 106 shows deviations exceeding the tolerance limit of 7 mm in height difference numbers 3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 39, 40, 41, 42, 67, 68, 69, 70, 71, 80, 81, 82, 105, 106, 107, 108, 109, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, and 119. The biggest deviations occur in height differences number 15 and 16 with value deviations +0.022 m.

4. Conclusions

The quality of the model both 2D and 3D affects the measurement of the height difference and gauge of the rail. Error factors in the model causes the possibility of the result of the rail gauge and height difference has potential error or not absolute. The solution to use a rail profile overlay model is quite helpful in interpreting the rail model according to its existing position so that points for vectorization can be determined.

Study of rail widening irregularities in curve no. 106 shows that 58% of the existing rail gauge have exceeded tolerance limits of +4 mm and -2 mm. The biggest deviation occurs in rail gauge number 24 with a deviation value of +0.017 m.

Study of rail cant irregularities in curve no. 106 shows 52% of the existing height difference numbers have deviations exceeding the tolerance limit of 7 mm. The biggest deviation occurred at a height difference number 15 and 16 with a deviation value of +0.022 m.

Based on the results of this study, some suggestions are submitted, especially to other researchers who will examine the same problems, methods, or instruments to minimize the shortcomings obtained from this research, namely, using a higher scanning resolution, using better registration method (some studies show registration with the target to target method with additional fine registration using the least square adjustment has a better level of accuracy than other registration methods), first test TLS scanning with different settings or compare which TLS is better for rail objects, using TLS phase shift (some studies show the acquisition of point cloud data with high accuracy for this type of TLS), do scanning at night (some studies obtain point cloud data with precision higher when done at night).

Acknowledgments

This research was supported by PT. Kereta Api Indonesia which has allowed to conduct research and provide the necessary data, as well as to PT. ASABA which has provided Terrestrial Laser Scanner tools.

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