Railway geometric design based on satellite imagery and digital terrain model

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Abstract. The purpose of research were (1) a conceptual, functional model designed and implementation for railway geometric design, (2) standard operational procedure made for railway geometric design using satellite imagery and digital terrain model, (3) calculated geometric information on the railway route so that fulfilling geometric national and international standard, (4) horizontal alignment drawing presented on the railway route, (5) vertical alignment drawing presented on the railway route. This research uses a descriptive method. Study location in South Sumatra Province, Indonesia. July 2016 to January 2017 is when conducting research. Calculation of horizontal and vertical geometry information using spatial analysis. Horizontal and vertical geometric calculated on railway route based on satellite image and digital terrain model could be faster, easier and cheaper than terrestrial and analog method.

1. Introduction

The research objectives were (1) designing conceptual, functional and implementation models for geometric railway design, (2) standard operational procedure made for railway geometric design using satellite imagery and digital terrain model, (3) calculated geometric information on the railway route so that fulfilling geometric national and international standard, (4) horizontal alignment drawing presented on the railway route, (5) vertical alignment drawing presented on the railway route.

The study presents an efficient method for automatic road extraction in rural and semi-urban areas. GIS update starting from color images and using pre-existing vectorial information are sought in this work. Data input required only satellite RGB bands or high resolution aerial color images. Four different modules: data pre-processing; Binary segmentation based on three levels of texture statistical evaluation; automatic vectorization by means of skeletal extraction; and finally the module for system evaluation was included in this system [1].

The assessment of the accuracy of using high-resolution stereo satellite imagery for extracting the highway profiles and plans and constructing accurate 3D highway visualization models is the goal of the construction of 3D digital highway models using IKONOS stereo satellite imagery. A number of ground control points acquired by global positioning system measurements are used for two stereo pair IKONOS satellite images for geo-reference Hong Kong and Toronto [2].

Spatial data collection and application in many aspects applied the Mobile Laser Scanning (MLS) systems widely. The railway applications had introduced with MLS technology and spatial data and efficiency were greatly enhanced when compared to traditional approaches. The railway environment did not completely apply the MLS technology advance [3].

3D, more D models and attached semantic information (attributes) are Digital Earth essential information. Engineers and scientists required very urgently techniques for generating efficient such
models. Image as the prime data source plays an important role in this context used for reality-based 3D modeling. A wealth of information that can be advantageously used for models generation contained in images. Satellite, air and terrestrial platforms increasingly provide images. If the process of model generation is to be automatized, we will encounter some of the problems which described briefly by this contribution [4].

One of the most useful functions in geographic information systems is finding a least-cost-path in the raster data format. Practical roadway planning did not have adequate existing algorithms. Considerations of spatial distances, anisotropic costs and the presence of bridges and tunnels in the paths are included into conventional algorithms to improve and develop least-cost path algorithms for roadway planning. Actual remote sensing and DEM data ran a new algorithm which implemented in JAVA. Realistic least-cost paths for practical roadway planning was produced from the results of experimental approaches of geographic information systems, actual remote sensing and DEM [5].

Some of requirements traffic engineers currently impose on digital terrain models from a practical point of view were presented by digital terrain models for road design and traffic simulation. Increasing the requirements of the Environmental Impact Analysis imposed by the European Union to be the cause of alignment of new road infrastructure must be carefully planned. National standards and engineering processes include linear alignment, cross sections of roads and adjacent roadside environments followed by the geometric design of the road by itself. The three-dimensional physical location of a road considering operational, economic and environmental requirements was determined by calculating horizontal and vertical road centreline [6].

A high level of maturity had been reached and huge map databases with a high coverage and up-to-datedness was used by today’s car navigation system. The database must enter driver information and an advanced warning system, more detailed and accurate information about the true geometry of the road because additional applications gain important. Engineers and scientists must acquire and integrate properties such as height; longitudinal and transverse slope, curvature, and width that is currently absent [7].

Safety concerns are addressed proactively by transportation agencies which implementing the Highway Safety Manual (HSM) at the state level. The Highway Safety Manual requires highway inventory data but is not sufficient highway inventory data which owned by the state departments of transportation (DOTs). Highway inventory data is collected for other purposes by state DOTs and local agencies which utilizing many techniques. The collection of dataset needed by minimizing costs and safety concerns is not yet known as efficient methods or any combination [8].

Identification and mapping of suitable highway construction site is the purpose of highway alignment project using remote sensing and geographic information systems. Remote sensing and GIS model for route location and highway alignment was developed and used to generate alternate highway route applications. The applications of alternate highway route resulted from the development and use of remote sensing and GIS model for route location and highway alignment. Topographic, environmental, built-up areas, and geological variables could be easily modeled by Geographic Information Systems. Numerous environmental issues need to be addressed in planning a new road or highway so that it is expensive and time consuming process. Compilation, management and display of data associated with geographic space could use GIS as a powerful tool. Digital map preparation and analysis purposed could be using GIS [9].

2. Methods
Spatial analysis used descriptive methods. As shown in Figure 1, analysis of the spatial form of the presentation of geometric information calculated on the railway route applied the descriptive method that go through stages, namely: (1) identified railway geometric design needs, (2) collected data (satellite imagery, digital terrain model, soil bearing capacity, geology, cadastral, land use, hydrology data, national railway standard), (3) grouped data by type and level, (4) designed conceptual model of data input, processing and output, (6) made functional model of data structures designed and database management, (7) implemented spatial development system, (8) converted digital terrain model and satellite imagery to contour map, (9) determined trace route of railway, (10) calculated and drew horizontal alignment based on coordinates of start point, point of intersection and end point on standard sheet I, (11) calculated and drew long section, super elevation diagrams, parabola vertical curves based on contour lines where fix trace route of railway passed on, (12) calculated and drew cross section, cut
and fill based on terrain surface and definitive railway elevation, (13) calculated and drew railway drainage system.

**Figure 1.** Flow chart of railway geometric design based on satellite imagery and digital terrain model

Railway geometric design needs identification consist of spatial (contour line, Universal Transverse Mercator coordinates, grid or graticule, raster and vector data) and attribute information components (land use, geology, cadastral, hydrologic, soil bearing capacity, population). Data type is primary and secondary data which were collected by activity of survey and documentation. Data grouped based on graphical and textual data. Each data was suitable grouped by data rank, resolution or map scale.

Base map and map sources were products of input data conceptual modelling. Spatial and tabular queries were products of processing data conceptual modelling. Thematic map and tabular analysis were products of output data conceptual modelling.
Type of features and field were products of data structures and data base management functional modeling. On screen digitizing and record input were products of spatial development system implementation.

Coordinates of study location were obtained from satellite imagery. Satellite imagery registered to ground control points and transformed to ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) digital elevation model. Contour maps were generated from DEM which having coordinates and heights data by triangulation with linear interpolation gridding method.

Contour maps were used for making 3 alternatives of railway route traces. One of requirements of railway route trace is not cutting 3 contour lines more based on horizontal alignment. Ratio of the areas of cut and fill were approaching 3 : 1 based on long section of vertical alignment.

Best trace of railway route was calculated horizontal distance and azimuth angle for obtaining point of intersection angle and turn horizontal curve type by geometric formulation. Railway engineer were calculating and drawing horizontal alignment based on coordinates of start point, point of intersection and end point on standard sheet I. They were calculating and drawing long section, super elevation diagrams, parabola vertical curves based on contour lines where fix trace route of railway passed on. Railway engineer were calculating and drawing cross section, cut and fill based on terrain surface and definitive railway elevation. Finally, they were calculating and drawing railway drainage system.

3. Result and Analysis

3.1. Map of Tanjung Enim Baru – Prabumulih

![Figure 2. Satellite Imagery Map of Tanjung Enim Baru – Prabumulih](image)

In Figure 2, satellite imagery map of Tanjung Enim Baru – Prabumulih gave geometric information, there are: UTM (Universal Transverse Mercator coordinates of polygon points from station 0+00 meter Tanjung Enim Baru to the end of station 76+113 meters Prabumulih). UTM coordinates data were used for calculating \( d_H \) (horizontal distance) and \( \Delta_{PI} \) (horizontal point of intersection angle).

| No | Station | Wide (meter) | Length (meter) | Elevation (MSL) Start Point | Elevation (MSL) End Point | \( \Delta_{PI} \) (°) | Horizontal Curve Type |
|----|---------|--------------|----------------|----------------------------|---------------------------|----------------|---------------------|

Table 1. Railway Geometric Calculation
Information which were presented are number of stationing, width of road, length or horizontal distance, elevation from mean sea level, point of intersection horizontal angle and horizontal curve type. If $\Delta PI < 30^\circ$ then spiral-spiral curve type chosen then if $30^\circ < \Delta PI \leq 60^\circ$ then spiral-circle-spiral chosen then if $\Delta PI > 60^\circ$ then full circle chosen as in Table 1.

Stationing, width and horizontal distance were calculated from satellite imagery map. Elevation was calculated from digital terrain model (DTM). Point of intersection horizontal angle was calculated from three points to gain horizontal direction angle (azimuth).

3.2. Map of Horizontal Alignment Design

![Image of Satellite Imagery Map of Horizontal Alignment Design](image)

**Figure 3.** Satellite Imagery Map of Horizontal Alignment Design

As seen Figure 3, satellite imagery map of horizontal alignment design gave coordinates of stationing points, existing land use, and railway trace plan and station location. Horizontal angle point of intersection and horizontal distance were calculated from coordinates stationing points.
Figure 4. Standard Sheet I (Contour Map and Long Section of Railway Trace)

Standard Sheet I were presenting contour map and long section drawing. Contour map was used to design fix railway trace which fulfil horizontal geometric national standard. Long section drawing was used to design fix railway elevation which fulfil vertical geometric national standard as seen in Figure 4.
3.3. Vertical Alignment Drawing

As seen in Figure 5, standard sheet II was presenting natural land elevation and fix railway elevation plan. If natural land elevation is bigger than fix railway elevation plan then calculated cut volume else fill. Formulation for calculating cut and fill volume are as follows.

\[ V_{cut} = \frac{1}{2} (A_{Icut} + A_{Ifill}) \cdot D_{H12} \] (1)

\[ V_{fill} = \frac{1}{2} (A_{Ifill} + A_{Icut}) \cdot D_{H12} \] (2)

- \( V_{cut} \) = Cut volume
- \( V_{fill} \) = Fill volume
- \( A_{Icut} \) = Cut area in first cross section
- \( A_{Ifill} \) = Fill area in first cross section
- \( A_{IIcut} \) = Cut area in second cross section
- \( A_{IIfill} \) = Fill area in second cross section
- \( D_{H12} \) = Horizontal distance from first to second cross section

**Figure 5.** Standard Sheet II (Cross Section for Cut and Fill Calculation)
4. Conclusion
A conceptual, functional model designed and implementation for railway geometric design could be resulting contour map, long section and cross section drawing. Standard operational procedure made for railway geometric design using satellite imagery and digital terrain model consist of horizontal geometric data from satellite image map and vertical geometric data from digital terrain model. Calculated geometric information on the railway route consist of horizontal distance, point of intersection horizontal angle, natural land and fix railway plan elevation, slope, cut and fill area. Horizontal alignment drawing presented on the railway route consists of spiral-spiral, spiral-circle-spiral and full circle curve turn type. Vertical alignment drawing presented on the railway route consists of vertical concave and convex curve, slope, natural land and fix railway plan elevation, cut and fill area.

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