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Original Research Paper

Automated pavement horizontal curve measurement methods based on inertial measurement unit and 3D profiling data

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ARTICLE INFO

Article history:
Available online 21 March 2016

Keywords:
Horizontal curve
Inertial measurement unit (IMU)
Curve radius
Kinematic method
Geometry method
Lateral acceleration method
ANOVA test
Curve safety analysis

ABSTRACT

Pavement horizontal curve is designed to serve as a transition between straight segments, and its presence may cause a series of driving-related safety issues to motorists and drivers. As is recognized that traditional methods for curve geometry investigation are time consuming, labor intensive, and inaccurate, this study attempts to develop a method that can automatically conduct horizontal curve identification and measurement at network level. The digital highway data vehicle (DHDV) was utilized for data collection, in which three Euler angles, driving speed, and acceleration of survey vehicle were measured with an inertial measurement unit (IMU). The 3D profiling data used for cross slope calibration was obtained with PaveVision3D Ultra technology at 1 mm resolution. In this study, the curve identification was based on the variation of heading angle, and the curve radius was calculated with kinematic method, geometry method, and lateral acceleration method. In order to verify the accuracy of the three methods, the analysis of variance (ANOVA) test was applied by using the control variable of curve radius measured by field test. Based on the measured curve radius, a curve safety analysis model was used to predict the crash rates and safe driving speeds at horizontal curves. Finally, a case study on 4.35 km road segment demonstrated that the proposed method could efficiently conduct network level analysis.

1. Introduction

Horizontal curves serve as smooth transitions between tangent sections of pavements, and are complex but unavoidable features for all roads (Calvi, 2015; Othman et al., 2012). Most crash studies indicated that road curves present a higher crash risk and a larger proportion of severe crashes than straight segments (Gibreel et al., 2001; Othman et al., 2009). As reported by the Federal Highway Administration (FHWA) Office

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2016.03.004

of Safety, 27% of fatal crashes occurred on horizontal curves in the years of 2006–2008 (FHWA, 2010). Therefore, determining curve geometry and its effects on accidents is one of the critical steps in safety studies of pavements on curves.

Previous studies and efforts show that radius measurement methods of pavement horizontal curves can be grouped into two categories: manual methods and automated methods. The manual methods include chord length method (Easa, 1994), compass method and plan sheet method (Carlson et al., 2005). However, the manual methods are time consuming, labor intensive, not suitable for network-level survey, and present a potential hazard for field operators (Chen and Hwang, 1992; Davis et al., 1996; Dong et al., 2007; Dubeau et al., 1995; Easa, 1994). Therefore, researchers or agencies are motivated to develop methods that can automatically perform horizontal curve identification and radius measurement.

Othman et al. (2012) devised an approach to derive path radius and identify start-end points of horizontal curves by using field operational test data. However, the field operational test needs to be conducted multiple times on one curve for accurate measurement. As a result, this method requires extensive labor and is not suitable for network-level survey.

In the study of Carlson et al. (2005), a ball bank indicator (BBI) was employed to measure the lateral acceleration, and the curve could be back-calculated based on the point-mass equation and radian measures. This method is based on the assumption that effects of vehicle body roll on measurements can be negligible, therefore the measurement accuracy is subjective to body roll angle. Moreover, this method is not suitable for network level survey since its implementation requires the establishment of the PC and PT stations on site prior to the test and the testing vehicles must be driven at a constant speed throughout the curve.

Imran et al. (2006) and Bogenreif et al. (2012) presented a method of incorporation global positioning system (GPS) information into a geographic information system (GIS) for the calculation of the radius, length, spiral length, and vehicle position of horizontal curves. In this method, the curve radius was computed by automatically extracting the arc and chord length of the curve from a GIS map. However, extensive labor is still required for this method, which hinders its application to network-level survey.

Few studies have been conducted on curve radius measurements at network levels since the previous data acquisition systems are incapable of continuously measuring required data sets at highway speed and most data processing systems cannot fulfill automated identification of the start and end points of curves (Ai and Tsai, 2014; Easa et al., 2007; Vatankhah et al., 2013).

This study presents an automated method for horizontal curve identification and radius measurement for network level application. To achieve this goal, the digital highway data vehicle (DHDV) is used to continuously collect inertial measurement unit (IMU) data, global positioning system (GPS) data, and distance measurement instruments (DMI) data, and 3D profiling data at high speeds up to 100 km/h. The horizontal curve is automatically identified based on the change of heading angle from IMU, and the curve radius is calculated by three methods, namely kinematic method, geometry method, and lateral acceleration method. The flowchart of the automated horizontal curves measurement is shown in Fig. 1. Finally, a 4.35 km pavement section with five horizontal curves is chosen to explore the effectiveness of the proposed automation in horizontal curve investigation and curve safety analysis. Results indicate the presented approach is capable of rapidly analyzing crash potentials, estimating safe driving speeds at horizontal curves, and identifying the hazardous curves.

2. Data acquisition

2.1. *Digital highway data vehicle (DHDV) with PaveVision3D*

DHDV, developed by the WayLink Systems Corporation with collaborations from the University of Arkansas and the

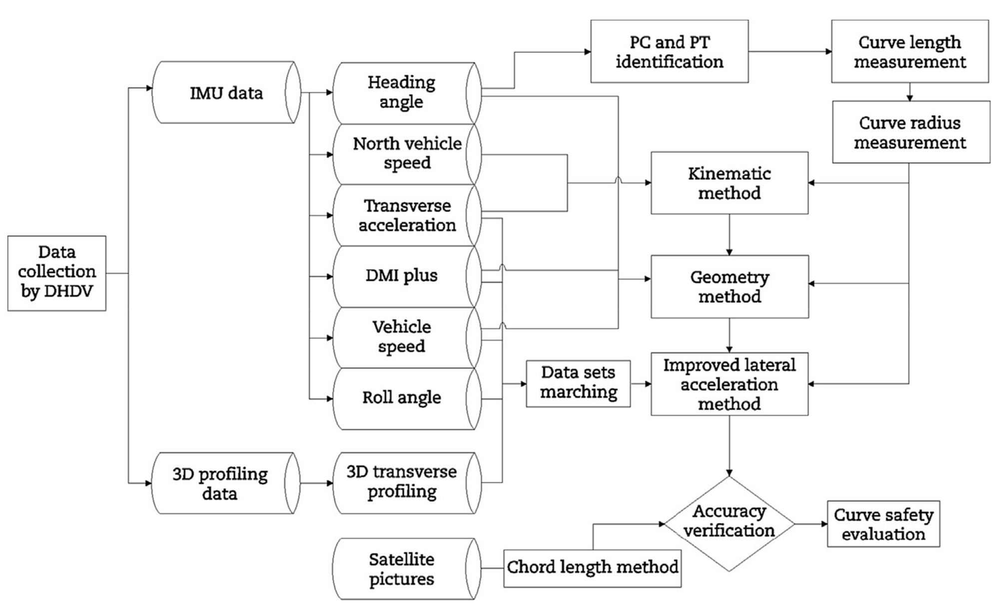

Fig. 1 – Flowchart of automated horizontal curve measurement.