Transportation Research Part C 79 (2017) 257–273

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Mobile mapping systems and spatial data collection strategies assessment in the identification of horizontal alignment of highways

G. Marinelli [a], M. Bassani [b,*], M. Piras [b], A.M. Lingua [b]

[a] NTNU – Norwegian University of Science and Technology, Department of Civil and Environmental Engineering, Faculty of Engineering, Høgskoleringen 7A, 7491 Trondheim, Norway

[b] Politecnico di Torino, Department of Environment, Land and Infrastructures Engineering (DIATI), 24, Corso Duca degli Abruzzi, Torino 10129, Italy

ARTICLE INFO

Article history:
Received 29 April 2016
Received in revised form 27 March 2017
Accepted 27 March 2017

Keywords:
Horizontal alignment
Geometric identification
Geographic information system
Inertial sensors
Global navigation satellite system
Low-cost sensors
As-built project

ABSTRACT

The horizontal alignment of existing highways may be identified by using several terrestrial or aerial geomatics technologies. Such technologies involve different levels of precision and accuracy; hence, different results can be expected. At present, there are no comparisons available between the solutions resulting from the use of different technologies and data sources for the same road alignment.

In this investigation, a number of terrestrial mobile mapping techniques and data collection strategies were evaluated. The centerline of a 3.6 km section of a highway was used to estimate radii, centers of curvature and orientation of tangents. Two statistical fitting methods were used to back-calculate these parameters, and the results were then compared with as-built alignment data.

Terrestrial images from a mobile mapping vehicle were used to determine the centerline, which was also estimated as the average line of the carriageway and pavement edges, and as the average line of the two driving trajectories. Positions were surveyed using low-cost sensors (an integrated GPS-IMU platform, HD webcam). For comparison purposes, aerial orthophotos and a GNSS (high-cost) receiver were used simultaneously. Although the GPS-IMU data and estimated trajectories provided results comparable to those of the GNSS receiver, the use of georeferenced images proved less accurate. The results and comments in the paper should be of use to survey practitioners when they need to select an acquisition methodology appropriate to the desired level of accuracy and in line with budget constraints.

1. Introduction

For several reasons, engineers need to establish the geometric characteristics of the elements forming the alignment of existing roads. This happens in the case of cadastral and surveying operations, to support safety and human factor studies, to control the quality of road construction, and more recently, in automotive engineering for Advanced Driver Assistance Systems (ADAS) and driverless vehicle applications.

* Corresponding author.
E-mail addresses: giuseppe.marinelli@ntnu.no (G. Marinelli), marco.bassani@polito.it (M. Bassani), marco.piras@polito.it (M. Piras), andrea.lingua@polito.it (A.M. Lingua).

http://dx.doi.org/10.1016/j.trc.2017.03.020
0968-090X/

Alignment identification consists of procedures aimed at the back-calculation of the geometric characteristics of the road from the collection of geospatial data of the road centerline. For some of the abovementioned applications, obtaining a precise spatial location of the various road elements (i.e., point of curvature, curve termini, vertexes), is less important than the estimation of geometric characteristics such as tangent orientation and length, radius of curvature, and spiral transition scale factor.

Road agencies do not always have complete geometric information on their infrastructures. In Italy, more than 85% of the 500,000 km network of existing roads was built before 1980 (Benedetto, 2000), the year in which CAD software was first used on microcomputers and employed in road design. Hence, alignment data information is unavailable for most existing roads. When available, the data are often reported in project drawings, thus time and effort are necessary to retrieve them in a format useful for numerical analysis and modelling. Furthermore, they may also differ from the actual current layout due to changes resulting from maintenance or reconstruction activity.

Engineers design the road alignment as a sequence of straight and curved elements. Following construction, a dedicated survey is usually carried out to determine the as-built alignment, which indicates the final position of the road on the ground. Any differences between the designed and as-built road alignments are attributable to inaccuracies of survey devices and construction operations. In addition, the as-built alignment is commonly assumed as coinciding with the road centerline marking, which in turn does not correspond to the designed roadway mid-line as a consequence of the inevitable distortions caused by laying operations. To avoid any erroneous evaluations, the as-built alignment may also be obtained by recourse to different strategies, i.e. averaging parallel lines that either delimit the roadway (both pavement or carriageway edges), or that are derived from the trajectories of survey vehicles collected by means of Mobile Mapping (MM) technologies.

The use of MM is promoted by many road agencies since data can be collected in a short time and updated very quickly (Findley et al., 2011). Alternatively, spatial data can also be collected from the interpretation of digital maps and aerial images, also using GIS tools. All these technologies involve different levels of precision and accuracy; therefore, when employed in the identification of the horizontal alignment, different results can be expected. At present, there are no comparisons available between the alignment solutions resulting from the use of different spatial data sources for the same road alignment.

The aim of the research was to test, evaluate, and compare different methodologies in terms of the survey devices (using both low and high-cost sensors), fitting algorithms and data sources used to calculate the center of curvature location and radius, as well as tangent direction of existing roads. This objective was pursued with the back-analysis of geospatial data points of the centerline marking, and also employed different strategies by averaging the survey vehicle trajectories in the two directions, as well as the two carriageway and two pavement edges.

Data was collected on a section of a two-lane rural road in the Northwest of Italy. The alignment of this section is characterized by combined curves (circular arcs with transition clothoids) with radii of 550 m and with different lengths and central angles. Data validation, by means of reference to the as-built project drawings, was carried out to verify the accuracy of the proposed data collection method.

2. Related work

One way to obtain spatial information on the horizontal alignment of roads is to use Mobile Mapping (MM) technologies (Harkey et al., 2004), where vehicles with sensors on board such as Global Navigation Satellite Systems (GNSS), laser scanners (LiDAR), digital cameras, Inertial Measurement Units (IMU), and integrated devices (i.e., GNSS-IMU) are used to collect spatial data (position, attitude, images and point clouds) while traveling along a road.

For this purpose, GNSS and IMU sensors have been employed by several authors to measure the vehicle trajectory or the position of the horizontal marking, which many assume to represent the centerline in the cross-section (Ai and Tsai, 2014). Geo-referenced imagery from digital cameras on MM vehicles were proposed for the detection of lane markings (López et al., 2010), and/or for the extraction of information to support road inventory activities (de Frutos and Castro, 2014). The level of accuracy attainable using these systems can range from centimeters to meters, depending on the technology used and the quality of the output signal.

Some of the past contributions to the detection of the horizontal alignment were made by averaging the data points collected along the two driving trajectories. In these contributions, it was assumed that the data collected along each path were located approximately in a symmetrical pattern with respect to the centerline. Drakopoulos and Örnek (2000) considered the quality of the extracted geometric information from Global Positioning System (GPS) surveys acceptable following a comparison with as-built data. The methodology was applied to a two-lane highway and proved effective even in the case of short curves with small deflection angles. Some difficulties arose with the identification of curves shorter than 300 m.

Crisman and Robba (2004) compared as-built data with those derived from the analysis of data collected by the MM vehicle. In the case of tangents and circular arcs, they observed good compliance, while in the case of spirals they concluded that the length and scale parameters were too sensitive to small differences between calculated and real values, thus leading to unsuccessful results even in the case of circular arcs with large radii and of short length. Choi and Sung (2006) corroborated this result since they found that the estimate of the clothoid scale parameter had a higher error range when compared with the geometric characteristics of tangents and circular arcs.