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A lane-level road network model with global continuity

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ABSTRACT

An increasing number of Intelligent Transportation System (ITS) applications require high accurate vehicle positioning, e.g., positioning at the lane-level. This requirement motives the development of modeling the road network at the lane-level. In this paper we propose a novel lane-level road network model. It can be considered an improvement to existing models in its capability of representing the road and intersection details at the lane-level in a uniform and precise way. As a result, the model can guarantee the global continuity for arbitrary map route, which better approximates the real vehicle trajectory. In addition, the map construction algorithms are also developed. Following the proposed methods, the lane parameters can be extracted efficiently under flexible precision requirement, and intersections with varying appearances can be precisely modeled with limited extra data. Experiments were performed to verify the proposed model in representing the lane-level geometrical and topological details of an urban area of Milan. The results also demonstrate the effectiveness of the map construction methods.

1. Introduction

A range of Intelligent Transportation System (ITS) applications and services such as the in-car navigation system and the fleet management system require continuous and accurate positioning information of vehicles traveling on the road network (Ochieng et al., 2009). A digital map is therefore a vital component that imposes constraints on the navigation solution and enables the systems to relate the positioning information with the physical location of the vehicle in the road network (Skog and Handel, 2009). Accordingly a fleet management system can track fleet vehicles and an in-car navigation system can determine the driving road and provide turn-by-turn guidance. Besides, more Advanced Driver Assistance Systems (ADAS) can benefit from a digital map which is applied as a 'predictive sensor' of the vehicle movement (Rowell, 2001; Toledo-Moreo and Zamora-Izquierdo, 2010).

To further improve the usefulness of these systems, the information associated with traffic lanes can be introduced. Recently, an increasing number of researchers have put their attentions on more advanced systems requiring vehicle positioning at the lane-level (Toledo-Moreo et al., 2009, 2010; Schubert, 2011; Williams et al., 2012; Vu et al., 2012). The capability of determining in which lane a vehicle is traveling will benefit a large number of vehicle navigation based applications. For example, the route planning can be concerned with the vehicle maneuvers across particular lanes

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Nomenclature

c	intersection index
$\mathbf{c}$	intersection
$\mathbf{C}$	intersection set of road network
d_H	Hausdorff distance
d_s	sample distance
e	precision dilution
$\mathbf{E}$	precision dilution set
f_{CHS}, g_{CHS}	function of Cubic Hermite Spline (CHS)
$f_{CHS}(u\|\mathbf{S})$	CHS curve parameterized by $\mathbf{S}$
f_{att}	function of lane attribute
g	objective function measuring the difference between joint lane and corresponding turning trajectory
$\mathbf{h}$	parametric curve
$\mathbf{L}$	lane set of road
$\mathbf{L}_r$	entering lane set of intersection
$\mathbf{L}_t$	exiting lane set of intersection
N_C	number of intersections in $\mathbf{C}$
N_L	number of lanes in $\mathbf{L}$
$N_{\hat{P}}$	number of position fixes in raw trajectory
$N_{\overline{P}}$	number of position fixes in sampled trajectory
N_R	number of roads in $\mathbf{R}$
N_λ	number of control points of lane
$\mathbf{p}$	location
$\hat{\mathbf{p}}$	raw position fix
$\bar{\mathbf{p}}$	sampled position fix
$\widehat{\mathbf{P}}_t$	vehicle turning trajectory
$\Delta\widehat{\mathbf{P}}_t$	differential of vehicle turning trajectory
$\widehat{\mathbf{P}}_\lambda$	raw trajectory of road lane
$\overline{\mathbf{P}}_\lambda$	sampled trajectory of road lane
$\mathbf{Q}_c$	intersection attribute
$\mathbf{Q}_r$	road attribute
$\mathbf{Q}_t$	joint lane attribute
$\mathbf{Q}_\lambda$	lane attribute
s	lateral sequence number of lane
$\mathbf{s}$	parameter associated with a control point
$\tilde{\mathbf{s}}$	modified control point (in joint lane generation)
$\mathbf{S}_0$	original lane parameter (before rarefying)
$\mathbf{S}_t$	joint lane shape parameter
$\mathbf{S}_\lambda$	lane shape parameter
$\widetilde{\mathbf{S}}_\lambda$	modified lane parameter (in joint lane generation)
$\overline{\mathbf{S}}$	set of removed control points (in rarefying process)
$\mathbf{S}'$	extension set of $\overline{\mathbf{S}}$ (in rarefying process)
$\mathbf{r}$	road
$\mathbf{R}$	road set of road network
$\mathbf{t}$	joint lane
$\mathbf{T}$	traffic matrix
u, v	variable of parametric curve
$\mathbf{v}$	tangent vector
$\tilde{\mathbf{v}}$	modified tangent vector (in joint lane generation)
$\mathbf{W}$	road network
ε	precision threshold
λ	lane index
$\boldsymbol{\lambda}$	lane

(e.g., the lane for exiting a highway) in a carriageway and provide detailed planning results to assist the driver in a complex road network. The transportation officials can determine differences in traffic conditions for different lanes using the data from probe vehicles (Du and Barth, 2008).

In order to achieve the functions of a navigation system operating at the lane-level, the accuracy of both the vehicle positioning and digital maps has to be improved. The positioning resolution has made significant progress with local differential