ROAD PRICING WITH GIS AND GPS POSITION [1]

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Abstract

Traditional types of road pricing include toll roads, congestion pricing, high occupancy toll (HOT) lanes, cordon (area) tolls, road space rationing, and vehicle use fees. A new GIS and GPS position charging scheme, which is able to integrate all the pricing types, is presented. System architecture consists of In-vehicle Unit (IU) and the Control Center System (CCS) for the scheme is described. Technical considerations in the system, including suitable road network database structure, integrated GPS positioning method, communication between vehicles and the control center, as well as the charge calculation methods are elaborated on.

1 INTRODUCTION

Traditional types of road pricing include toll roads, congestion pricing, high occupancy toll (HOT) lanes, cordon (area) tolls, road space rationing, and vehicle use fees. There are a lot of methods can be used to collect transportation pricing fees. These methods differ from each other significantly in terms of their costs, convenience, and price adjustability. Consumers generally prefer pricing techniques that are easy to understand, convenient and quick to use, and allow them to pay for just the amount of vehicle travel. Table 1 gives a description of different road pricing methods. Compare with other methods, GPS and digital map based pricing can incorporate virtually any pricing factor and it can be the most accurate pricing system.

A new charging scheme based on GPS and digital map is presented. The new scheme charging will be based on distance vehicle traveled in different areas determined by integrated GPS positioning and digital road network database. This makes the new system not only more consistent with road pricing principles and objectives of reducing traffic congestion and air pollution, but also more flexible for the integration of road pricing system with other Intelligent Transportation Systems (ITS) such as emergency assistant and dynamic traffic assignment. At the same time, it has lower capital investment and operating costs, and is relatively simple to implement and modifying with the expansion of charging areas and changes of traffic conditions due to nondependent on gantries as current system.

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Pricing method	Cost of equipment	Cost of Operation	User convenience	Flexibility
Pass	Low	Low	Medium	Low
Booths	High	Medium	High	Medium
ETS	High	Medium	Low	High
OVRS	High	Medium	Low	High
GPS/GIS	High	Medium	Low	High

Table 1 Comparison of different pricing methods

2 STRUCTURE OF THE SCHEME

To meet the requirements of an effective and fair road pricing system, the characteristics should be reflected from different perspectives. The users always hope the system is easy to understand, convenient (i.e. does not require vehicles to stop at toll booths), different options (alternative modes, travel times, routes, destinations), payment options (cash, prepaid card, credit card, etc), transparent, and anonymous. The traffic authority wants the system to be less traffic impacts, efficient and equitable, flexible, reliable, secure and enforceable, cost effective, minimum disruption during development phase and can be expanded as needed. From the society's perspective, it is to be positive net benefits when all impacts are considered, politically acceptable, positive environmental impacts, and easy integration with the same charging system such as parking, public transit, etc. The proposed GPS and digital map based road pricing scheme is the best method to balance the requirements from different perspectives.

The new GPS and digital map based road pricing scheme consists of In-vehicle Units (IU) and the Control Center System (CCS). The block charts of IU and CCS are shown in figure 1 and figure 2 respectively.

The IU provides continuous vehicular position determined by integrated GPS/Dead Reckoning (DR) positioning device and transmits it with vehicle ID to CCS. Data fusion is mainly for fusing all the sensors' data to get more accurate, robust positioning information. Display function shows related information to the driver, such as guidance, charging information or map interface. Transceiver provides two-way data link via wireless network and IP based packet data transmission. The data would be broadcast into the Internet so that any authorized user can make full use of them to provide value-added services. Smart card interface is for charging via pre-paid smart card.

CCS is functioned to track, monitor, charge, and provide guidance to all vehicles traveling on the road. Charging is based on the road links vehicle traveled matching with map database and determined charging standard. Charging standard is available on Internet for all drivers. It can also be checked through IU if it is functioned. Upon receiving the vehicle position, CCS matches vehicle trace with the road links through map matching and calculates the vehicle cost. Payment can be made through smart card in IU immediately afterward or later on monthly based.

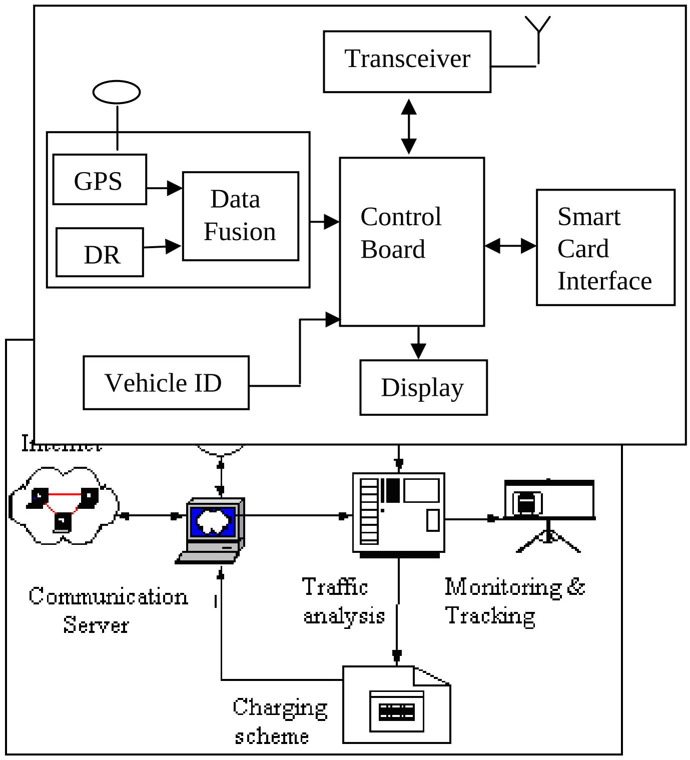

Figure 2 Control Center System

3 ROAD DATABASE DESIGN

Efficient map data model can improve the algorithms such as map matching and route selection that depend on map data. The node/link planar and non-planar models are effective data models and the planar model is currently one of the most commonly accepted models because of its least complexity and most efficiency. Besides, the planar model and the real road or street map is conceptually similar. It is also an effective model to meet the needs of new charging scheme of 'link by link'.

In our database, the road network is composed of two elements, links and nodes. Every road intersection must be indicated by a node and road between nodes is a link. Link is a single line representation of the road. Associated with each link and node will be a set of attributes, conceived as the entries in one row of a list of rectangular tables. A graphical represented network of figure 3 can be modeled in several tables as shown in table 2, table 3, and table 4. Different from usual ones, the link table contains a price field to sign the corresponding link cost. In order to improve the efficiency for the navigation system, a unique hierarchical database structure is designed to divide the map into layers and regions.

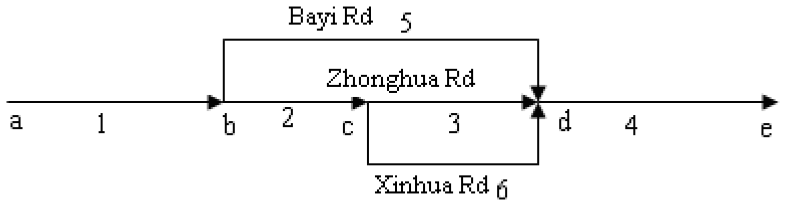

Figure 3 A graphical represented road network

ID	Road	Payment standard
1	Zhonghua Rd	2
2	Zhonghua Rd	2
3	Zhonghua Rd	2
4	Zhonghua Rd	2
5	Bayi Rd	1
6	Xinhua Rd	1

Table 2 Link table for road pricing

ID	Red light
a	n
b	y
c	y
d	y
e	n

Table 3 Node table

4 MAP MATCHING METHOD

Map matching algorithm in CCS processes the received vehicle position and searches the map database to create the list of road links the vehicle traveled. The required payment is calculated according to the road link price in database and deduction is made from prepaid card or stored to the vehicle ID account for monthly-based payment.

ID	Road	Lanes	Start node	End node
1	Zhonghua Rd	4	a	b
2	Zhonghua Rd	4	b	c
3	Zhonghua Rd	4	c	d
4	Zhonghua Rd	4	d	e
5	Bayi Rd	2	b	d
6	Xinhua Rd	2	c	d

Table 4 Topology between links and nodes

Different from vehicle navigation system (5), map matching for road pricing does not require real time calculation. This means that the searching of road link vehicle traveling on current can use not only the past and present vehicle position but also the following vehicle position. The off time matching makes it much more accurate and reliable. The matching processes (as shown in figure 7) are: initialization (O), position between intersections (M-N), position near intersection and no turn detected (M), position near intersection and turn detected (P), and re-initialization.

A probabilistic algorithm is designed to match the initial position of the vehicle. Since the actual location of the vehicle is never precisely known, so we determine an error ellipse, i.e. confidence region, that vehicle is likely to be within. From estimation theory, the input and output signals can be modeled as stochastic process. Variable associated with the true and measured values can be modeled as random variables. Variance-covariance information is propagated through appropriate algorithms to derive the variances and co-variances as functions of the original random variables or as functions of parameters estimated from the original observations. These variances and covariances are used to define confidence region. The determination of the confidence region should also consider the map accuracy as well as the road width.

Searching process proceed until there are candidates within the region. A match completed if there is only one road link cross or within the region. If more than one candidates exist, the candidates are eliminated with the following standards until the only correct link is matched: direction difference between road link and vehicle traveling, traffic restrictions such as one-way road, distances between vehicle position and candidate link. One matched link can be used to verify the immediate past link with their topology relationship.

After a valid start point is known, only three situations are to be considered: vehicle on a road link between intersections, vehicle near an intersection while no turn is detected, and vehicle near an intersection while a turn detected.

Suppose the route traveled is O-M-N-P-Q, the map matching processes are as following (figure 4).

- Matching the start position to initial location O on link L1, record the distance OM by GPS and DR distance sensor.
- When vehicle near node M, three possible connections are considered and match to link L2 while no turn is detected at M.
- Among 3 possible connections at N, when a turn is detected, link L3 is selected according to azimuth measurements or angle turned.
- Repeat the same processes above.
- The vehicle trace recorded is L1-L2-L3-L4, …

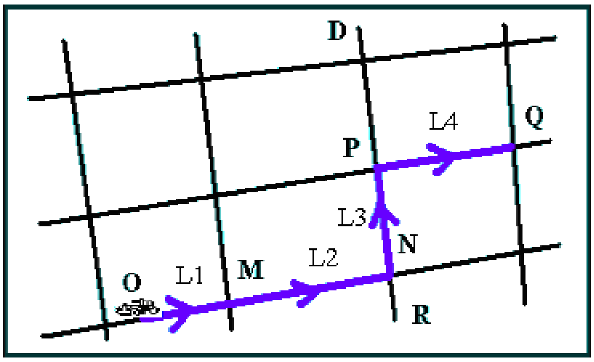

Figure 4 Map matching process

Suppose the recorded links in one month for a vehicle are Li (i=1,2,3, … , m), then the monthly payment P for the vehicle can be calculated according to price scheme in the database,

$$P = \sum_{1}^{m} price(L_i)$$

5 SUMMERY

GPS and digital map based road pricing scheme is proposed and technical solutions are investigated. Compare with the currently used ERP systems, The GPS and digital map based system has the advantages of lower operation cost, more user convenience, more flexibility and easier integration with other ITS systems.

Despite the technical feasibility, more investigations are necessary on issues for implement GPS and digital map based road pricing. These include integration of road pricing with other ITS systems, price criterion, possible influences on travel behaviors, privacy concerns, and relative vehicle policies.

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