TOWARDS AREA-WIDE TRAFFIC MONITORING-APPLICATIONS DERIVED FROM PROBE VEHICLE DATA

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Comprehensive, up-to-date traffic monitoring is the basis for mobility information and traffic management systems. However, conventional stationary traffic data measurements are hardly able to provide the necessary data for an area-wide monitoring and cannot deliver enough information for many traffic related services. Therefore an alternative approach using positioning data of commercial vehicle fleets for traffic monitoring issues has been established.
This paper surveys different prototype applications based on this probe vehicle data. Continuous monitoring and information of traffic situation via the World Wide Web accomplished by jam detection and highlighting is the basic service. Further on, vehicle route guidance systems using current and historic data achieve superior performance. Such guidance systems have been tested as modules for dynamic navigation and fleet disposition system. Finally a method to derive digital road maps and street characteristics from positioning data is presented.

Introduction

During the last decade, a lot of mobility services have been developed. Nevertheless, the expected commercial impact was not achieved, user acceptance is still quite low, and few people are willing to pay extra fees. Analysing these facts is obviously beyond the scope of this paper, but poor performance of some services due to lack of appropriate data is certainly one important issue. Therefore, establishing a reliable, area-wide traffic monitoring system is the basic step towards effective traffic information and guidance services.
However, especially in urban areas, the standard approach of using stationary traffic volume measurements like inductive loops, infrared sensors or video observations is incapable to provide necessary data for all the major roads. An alternative, more reliable and cheaper method is based on Probe Vehicle Data (PVD) using positioning techniques, in general the Global Positioning System (GPS) and mobile data communication. Establishing a private car fleet of sufficient size is not only a monetary problem of equipping the vehicles with GPS receivers and paying the communication fees, but also a problem of protection of data privacy. On the other hand, GPS-based vehicle tracking have been used by many car fleet operators for several years for fleet disposition purposes. After processing this data and eliminating its business-specific components, the data can be exploited to aid traffic management systems [Kühne 2003]. This new method is especially beneficial for regions with a poor traffic monitoring infrastructure because the necessary monetary

effort to establish such a system is very small in comparison to conventional systems and it is flexible and easily adaptable to other regions. Particularly, emerging markets like China with a fast-changing road network and a high penetration of latest information technologies on one side but with serious foreseeable traffic related problems on the other side can surely profit from this approach.
The paper presents a couple of prototype mobility services for some large European cities based on PVD of taxi-fleets. For more than two years several million PVD from some hundred taxis in five cities have been recorded and analysed continuously. The pre-filtered data is stored in a data base and serve as an important complement for times or areas suffering from low current data penetration. Such periods and regions can be treated by utilising statistical analysis on the time-dependent historical database.

Traffic Quantities Derived from Taxi Probe Vehicle Data

The taxi PVD is transmitted by the taxis periodically. Each data record contains a taxi identity number, time stamp, GPS position, taxi status (occupied, empty, waiting, etc.). The data is sampled typically every 30s. The detection rate allows a good identification of taxi trajectories along the road network.
In a first filtering step, the data is separated by coherent taxi trajectories; data not relevant for traffic analysis (e.g. from taxis waiting for customers) and not plausible data (e.g. mismatched GPS-positions) are eliminated. The second step of analysis is a map matching process where the position data are matched on a digital road map. (If such a map is not available a road network can also be generated from the PVD themselves, see below).
From the data a lot of information about the traffic situation is used for two purposes. First it is possible to conclude on the recent traffic situation in a city in general on a number of major roads. Second, data cumulated over a certain time period can give information about the typical traffic situation in nearly each road of a city at any given time of day.
Analysing the PVD database showed a fraction of taxi traffic on total road traffic in the investigated cities of 1 to 1.5%. This value is much higher during the night and decreases to about 0.7% during the morning peak hours. To provide data of an equivalent standard to roadside detectors (according to congestion detection) around 1% of the vehicles would be needed as probes [Chen 2001]. Taxis do not always and everywhere reach this fraction. Nevertheless this taxi-PVD penetration already allows development and testing of the derived mobility services and applications.

Traffic Monitoring

A basic mobility service is to inform the traveller about the current or a forecasted traffic situation. Therefore an internet information platform monitoring the travel times or the Level of Service (LOS) of the underlying road network was developed. It shows a map where the roads are coloured according to the ratio of their actual passing time to the passing time arising from their speed limit (see Figure 1).

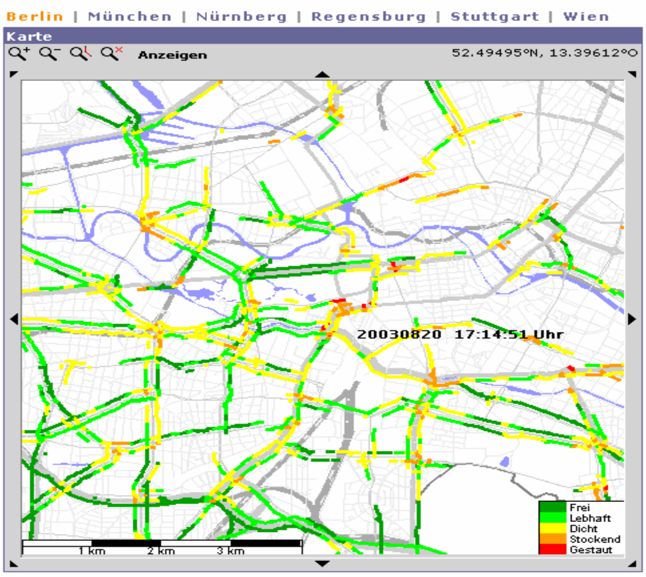

Figure 1: Traffic monitoring for Berlin city centre on 2003-20-08, evening rush hour

Automatic Congestion Detection

For non-graphical media like radio or teletext the current situation has to be filtered for congestions which are worth reporting.
Therefore, a congestion detection algorithm was implemented. The algorithm detects a congestion, if the travel time on a route exceeds the expected travel time by a significant factor (here: 50%) and by a significant amount (e.g. 10 min). The search can be limited to the higher-ranking road net. Compared to congestion reports given by travellers verbally e.g. to radio stations, the automatically generated congestion reports obtain a higher reliability and information content (e.g. passing time may be send along).

Dynamic Routing

The publication of the actual traffic situation assists the traveller in his route selection. However, a major objective of Advanced Travellers Information Systems (ATIS) is to give route guidance to the traveller. Therefore navigation systems in terms of on-board or off-board devices have been developed and became popular.
However, most existing solutions doesn’t use real (actual or historic) traffic data for routing. Often, the expected travel time on a road is estimated using a static speed value based on the speed limit, which is very imprecise.
In this study the usage of traffic data collected by probe vehicles for route guidance was investigated. Therefore a web server was developed which supports route planning based on current and historical PVD.
A wide range of factors influences the route choices of individuals. However, the most important factors are travel time and distance. For routing, a Dijkstra algorithm was implemented using travel time and/or distance-weighting factors for optimising the cost function. These factors are selectable by the user and express his willingness to drive longer routes for saving time.

Besides travel time and distance the variability of travel times is a further route selection criterion for travellers. Often constraints exist on arrival time at destination (e.g. reaching a flight at the airport). In these situations a traveller may prefer a route with a slightly longer, but more reliably estimated travel time. PVD is a suitable source for travel times as well as for their variability. As a next step a corresponding term will be added to the cost function.
The advantage of dynamic routing based on PVD was evaluated as follows: for several thousand randomly selected origin destination pairs in Vienna the fastest routes were calculated using PVD and using static data (speed categories from Navtech Corp.) respectively. For about 80% of the pairs the routes differed. The expected travel times along the routes were calculated based on PVD. For the PVD based routes the travel times were in average 4-5% less then on the routes calculated without PVD, and the distances were on an average 2% longer. Figure 2 shows the travel time saving and the distance increase as a function of the route length.

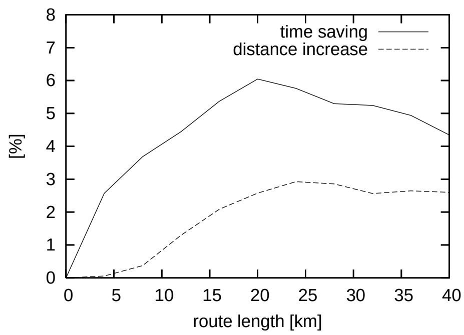

Figure 2: PVD-based routing vs. static routing

The web server mentioned above is accessible online via www.cityrouter.net. For mobile devices like PDAs and Java-enabled phones a Java application is downloadable from this site. A WAP version can be accessed via www.cityrouter.net/wap.

Off-board Navigation

As mentioned above, dynamic routing based on PVD can be made accessible from mobile devices like PDA's in a straightforward way via mobile internet (e.g. GPRS). Furthermore these devices can easily be enabled to determine their own position, normally by a adding a GPS receiver. By combining dynamic route information and the knowledge of the current position a navigation system can be developed.
In the context of this study a prototype of an off-board navigation system using PVD was implemented. Both visual as well as acoustic route guidance is offered by the system. Since the route is calculated on the server side, little computing power is needed on the PDA side. Furthermore the digital road map is needed only on server side, which simplifies the updating procedure.

Creation of Digital Road Maps

Wherever vehicle navigation, route guidance or a microscopic traffic simulation is used it relies on digital road maps. Additionally, infrastructure assessments and GIS-based analysis often require a digital representation of the road network.

At present, nearly complete West-European and North-American road nets are available as digital maps. But the coverage of other regions in the world is still very patchy. Also the maps might become inaccurate quite fast, especially in regions with rapidly changing infrastructure, and it is therefore a special challenge to keep them updated. Standard procedures to produce digitized road maps are very expensive and time consuming.

We propose a new methodology to derive digital road maps and street characteristics from ordinary taxi-PVD. First of all, the raw GPS data is filtered to eliminate improper data. To allow the application of statistical methods, the data is transformed to GPS hit density per unit square for the region of interest. Further on, filtering algorithms exploiting local statistics [Lee 1986] are used for padding and denoising. To derive basic street objects, a thinning algorithm was applied [Pavlidis 1982]. This procedure leads to a skeleton of the street net. For simplicity, the vectorized objects are composed of linear segments. Therefore, linear fitting is iteratively performed by minimizing the chi-square error statistic and resampling the objects toward a convergence criterion. The postprocessings steps are rule-based algorithms to correct the obtained digital maps. Depending on user needs, it can include edge and knot merging, connecting to nearest knots or edges, shortening or even deleting of implausible segments. An example of an automatic PVD-based road generation for a test area of approximately 6x6 km^2 in the city centre of Berlin is shown in Figure 3a. For comparison, Figure 3b shows the same area in a commercial digital map. As seen in these figures, the overall structure of the city road net is completely recovered by our method. All major roads can be identified, whereas various minor routes are only partly recognised because of low data penetration. Beside the road network topography a number of street attributes can be derived. In Figure 3a the identified multi-lane segments of the test area are marked with thicker lines.

Although the quality of the obtained results cannot compete with the standard techniques, the method has several advantages. Wherever GPS data from vehicles is available, a low-cost map can be produced just in time. It is especially well suited for error recognition within maps and to supplement expensive updating procedures of already existing digital road maps.

a b

Figure 3: a) Automatically generated digital road map of Berlin city centre, thick lines indicate recognised multi-lane roads, **b)** Same area, NAVTECH® road network

Conclusions

The paper described a couple of PVD based vehicular traffic applications and services. The new data collection and analysing methods result in better performance of the services, enhance the scope of the services and hopefully enlarge user acceptance. All of the proposed solutions are prototypes and not all of them have been extensively tested up to now. Certainly, specific data processing methods need further research, some refinements and calibrations. Additionally, some applications still suffer from insufficient data penetration. Nevertheless, the approach is very general and it is very likely that PVD availability will sharply increase in near future and will enhance the quality of services.

References

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