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EcoTour: Reducing the Environmental Footprint of Vehicles Using Eco-Routes

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***Abstract*—Reduction in greenhouse gas emissions from transportation is essential in combating global warming and climate change. Eco-routing enables drivers to use the most eco-friendly routes and is effective in reducing vehicle emissions. The EcoTour system assigns eco-weights to a road network based on GPS and fuel consumption data collected from vehicles to enable eco-routing. Given an arbitrary source-destination pair in Denmark, EcoTour returns the shortest route, the fastest route, and the eco-route, along with statistics for the three routes. EcoTour also serves as a testbed for exploring advanced solutions to a range of challenges related to eco-routing.**

I. Introduction

We are witnessing a range of efforts across the globe aimed at reducing greenhouse gas (GHG) emissions in order to combat global climate change.

For example, both the EU [1] and the G8 [2] have committed to a 50% reduction in GHG emissions by 2050. The emissions from transportation account for a substantial portion of all GHG emissions, and vehicular transportation generates two-thirds of transport-related GHG emissions [3]. Thus, it is crucial that vehicular transportation achieves substantial reductions. Eco-routing [4] is a simple yet effective approach to reducing vehicle fuel consumption and thus GHG emissions. Studies suggest that it is possible to achieve GHG reductions in the range 8–20% in various settings by providing eco-routes to drivers [5]–[7].

Notably, neither the shortest nor the fastest routes generally have the least environmental impact. For example, a case study [7] finds that the eco-route has a 9% longer travel time than the fastest route, but achieves a 9% reduction in fuel usage compared to the fastest route. Eco-routing relies on a weighted graph representation of the road network, where the edge weights capture the environmental impact (e.g., GHG emissions and fuel consumption) of traversing the edges. Once a weighted graph is available, eco-routes can be computed using existing routing algorithms, e.g., Dijkstra's algorithm or the A^* algorithm.

We present EcoTour, a system that annotates an OpenStreetMap (OSM) [8] representation of a road network with eco-weights (in addition to distance and travel time) based on GNSS (global navigation satellite system, e.g., GPS) and fuel consumption data, called CAN bus data, obtained from vehicles that travel in the road network, thus enabling eco-routing. EcoTour also serves as a testbed for exploring advanced solutions to a range of challenges related to eco-routing. EcoTour currently annotates the whole road network of Denmark (consisting of ∼630,000 segments) with eco-weights (as well as time-weights) based on more than 37 million CAN bus and 1.2 billion GPS records from 11,000+ vehicles. We are unaware of other systems capable of providing comprehensive and scalable eco-routing for an entire country.

II. EcoTour System Overview

Fig. 1 gives an overview of the EcoTour system, which consists of four modules: *pre-processing*, *weight annotation*, *route computation*, and *visualization*. The **pre-processing**

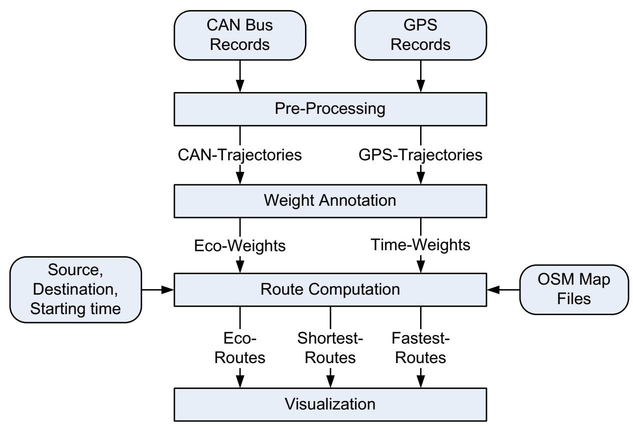

Fig. 1. EcoTour Overview

module takes as input either GPS or CAN bus data with corresponding GPS data. In our setting, CAN bus data is fuel consumption data obtained from the controller area network buses of vehicles. After map matching the CAN bus (GPS) data onto an OSM map, CAN-trajectories (GPS-trajectories), which are sequences of CAN bus (GPS) records, are available.

A CAN bus record r is of the form $r = (t, l, s, f)$, where t is the time of the observation; l and s indicate the location and the map matched segment at time t, respectively; and f records the total fuel usage until time t. A GPS record has the same format, but field f is empty. Fig. 2 shows a CAN-trajectory (r_1, r_2, r_3, r_4) on a road network, where r_1 and r_2 are map matched to segment (v_1, v_2), and r_3 and r_4 are map matched to segment (v_2, v_3).

The **weight annotation** module annotates segments with eco-weights and time-weights based on the CAN- and GPS-trajectories, respectively. We focus on how to derive eco-weights based on CAN-trajectories; deriving time-weights is

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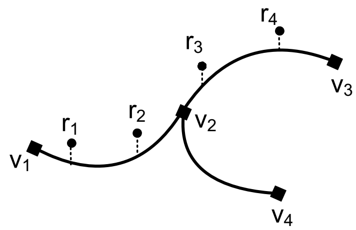

Fig. 2. A CAN-Trajectory

done similarly. Given a segment e, let $Set(e) = \{r_i | r_i.s = e\}$ contain all CAN bus records map matched to the segment. The eco-weight of segment e is computed as the length of segment e multiplied with the average fuel cost per unit length obtained from $Set(e)$, as shown in Equation 1.

$$length(e) \cdot \frac{1}{|Set(e)|} \cdot \sum_{r_i \in Set(e)} \frac{r_{i+1}.f - r_i.f}{dist(r_{i+1}, r_i)} \qquad (1)$$

Record r_{i+1} is the next record in r_i's CAN-trajectory; if r_i is the last record, r_i is ignored. Function $length(e)$ returns the length of segment e, and $dist(r_{i+1}, r_i)$ returns the road-network distance between records r_{i+1} and r_i. For example, the eco-weight of segment (v_1, v_2) in Fig. 2 equals

$$length((v_1, v_2)) \cdot \frac{1}{2} \cdot (\frac{r_2.f - r_1.f}{dist(r_2, r_1)} + \frac{r_3.f - r_2.f}{dist(r_3, r_2)}),$$

and the eco-weight of segment (v_2, v_3) is

$$length((v_2, v_3)) \cdot (\frac{r_4.f - r_3.f}{dist(r_4, r_3)}).$$

Given a source-destination pair, the **route computation** module applies Dijkstra's algorithm, implemented by PostgreSQL's pgRouting GIS extension, to compute the eco-route (the fastest route) based on the road network with eco-weights (time-weights) obtained from the weight annotation module. Finally, the **visualization** module tiles the OSM map according to Google Map's coordinate system and visualizes routes on top of Google Maps. Five layers, each with 184,153 tiles, are available, covering morning congestion, afternoon congestion, morning speed, afternoon speed, and free-flow speed.

EcoTour also serves as a **testbed** for exploring advanced solutions to a range of challenges related to eco-routing, including the following.

Time Varying Weights: Traffic in a road network varies substantially across time, which calls for time varying edge weights. We divide a day into 96 15-minute intervals and distinguish weekdays from weekend days. When computing eco-weights (time-weights) for a particular interval, only the CAN bus (GPS) records obtained from the interval are considered.

Dealing with Cold Segments: To compute routes, all segments must have weights. However, only 8% of the segments in our road network have CAN bus data (80+% have GPS data), and 98% of the segments do not have enough CAN bus records to derive accurate eco-weights. A segment is cold during interval I if it has less than 10 CAN bus records during I. To assign a weight to a cold segment, we take into account records as follows until enough records are available: (a) records obtained from the same segment during the entire day; (b) records obtained from segments that have the same road category[1] as the segment during I and then during the entire day; (c) all available records. Alternative approaches include considering records obtained from segments with road network topologies that are similar to that of the cold segment.

Uncertain Weights: For some segments, a single-valued weight, e.g., computed based on Equation 1, does not accurately capture the environmental impact of traversing the segments. For example, Fig. 3 shows the percentages of observations of different fuel usages observed on a segment. For such segments, higher-quality modeling is achieved by

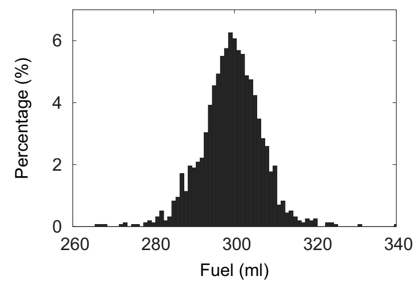

Fig. 3. Fuel Usage Distribution on a Segment

modeling the weight as a distribution in the form of either some kind of histogram or a probability density function, e.g., a uniform or a Gaussian distribution.

Real-Time Prediction of Near-Future Weights: Time varying weights are capable of modeling periodic variations in eco-weights, but are incapable of dealing with unusual events. When such events occur, it is important to be able to compute eco-weights for near-future time intervals based on data capturing the current traffic condition, instead of using weights computed using historical data.

III. Demonstration Outline

EcoTour has a web interface that includes a panel for entering queries and a digital map for visualizing resulting routes, as shown in Fig. 4. We proceed to describe how demonstration participants can interact with EcoTour to experience various routing services. EcoTour is also publicly available at http://daisy.aau.dk/its/.

The three buttons at the top of the data entry panel (see Label 1 in Fig. 4) enable the participants to configure EcoTour to compute the shortest route, the fastest route, and/or the eco-route. The participants are able to choose arbitrary locations in Denmark as source and destination (Label 2 in Fig. 4). In the figure, pins A and B are chosen as the source and destination. The trip starting time can also be specified in the data entry panel (Label 3 in Fig. 4).

Having chosen a source and destination pair and a starting time, three routes are computed and visualized. Fig. 4 shows the shortest route, the fastest route, and the eco-route from A to B. The eco-route shares some segments with the shortest route in the beginning, but then uses different segments. The fastest route and the eco-route are very different, as the fastest

[1]We use the 15 road categories defined in OSM.

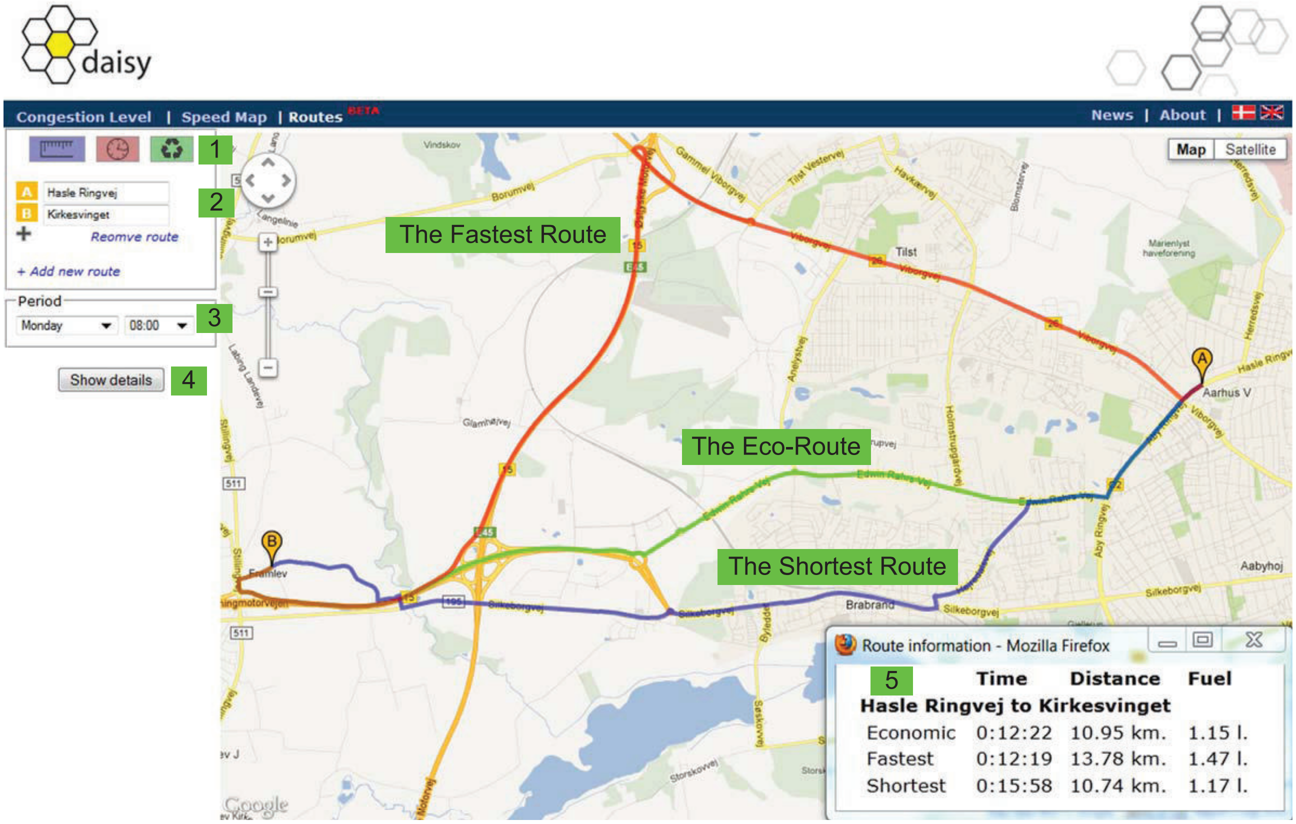

Fig. 4. User Interface of EcoTour

route uses highways and makes a big detour. This illustrates that the eco-route is not necessarily the fastest or shortest route.

Using the "Show details" button (Label 4 in Fig. 4), demonstration participants can obtain detailed statistics on the different routes. For instance, statistics on the three routes from A to B is listed (Label 5 in Fig. 4). The eco-route uses slightly longer time than that of the fastest route and travels slightly longer distance than that of the shortest route, but consumes the least fuel.

Demonstration participants will be able to learn details on how the EcoTour system is implemented using an exclusively open-source based software stack and how it is integrated with Google Maps. In addition, participants will receive information on the key challenges in obtaining a useful system, including the extensive data cleaning that eliminates some 40% of the GNSS data, and the tuning that renders PostgreSQL's pgRouting package capable of computing the various routes in interactive time.

IV. Conclusion and Outlook

We demonstrate how EcoTour turns GNSS and CAN bus data into time varying eco-weights and thus enables eco-routing. It is of interest to explore further how to assign eco-weights based on only GNSS data and to integrate uncertain eco-weights and real-time eco-weight updates into EcoTour.

Acknowledgments

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