Eco-friendly Routing based on real-time Air-quality Sensor Data from Vehicles

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Abstract

Recently, major cities are facing air pollution problems mostly caused by individual car traffic. Besides the emission of greenhouse gases, particulate matter is a particular concern for public health. In order to mitigate these emission related issues, we developed an environmentally friendly routing approach, which calculates the most fuel-efficient route - based on the driving dynamics of the road, vehicle, and traffic characteristics. In addition, the calculated route is designed to avoid regions of high particulate matter concentration. In order to integrate real-time air quality data of moving and stationary sensors using OGC Sensor Observation Service. Cars are used as moving sensors in the city. The paper evaluates the effects of air quality (particulate matter & greenhouse gases) on the route calculation - so that cars/bikes may receive real-time recommendations to avoid polluted areas.

1 Introduction

According to the World Health Organization (WHO) air pollution is one of the biggest environmental risks to health [19]. In 2012, approximately 3 million people worldwide died from heart disease, lung cancer, strokes, lung and respiratory problems caused by air pollution [19]. One of the main causes of air pollution is road traffic that emits greenhouse gases (GHG) and is one of the major sources of particulate matter (PM) [3, 16]. Urban environments are very prone to high emission levels, especially when public transport is not well developed and cars are the main mode of transportation. Air pollution may harm pedestrians, cyclists and other citizens alike. Hence, cities are trying to mitigate these problems with smart solutions. First, air quality is monitored with the help of air quality sensors, which can be mobile or stationary. On the basis of air quality indexes, it is possible to assess the air quality. In addition, vehicles already have such sensors that constantly evaluate air quality - as part of the ventilation system [9]. If the incoming ventilation air is polluted, the fresh air flaps are closed and no more air is drawn in from the outside. This source of real-time air quality measurements is not utilized to date.

Based on these real-time measurements - in combination with contemporary stationary measurements - car routes could be re-planned so that they circumvent areas with high

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air pollution and use a route with the lowest possible CO_2 emissions. In addition, citizens (cyclists, pedestrians) could be notified if they are about to enter an area of poor air quality - being PM or GHGs. This research work is concerned with the question if real-time air quality vehicle sensor measurements have an effect on eco-friendly routes. Hence, we look on how polluted areas - high PM values in this context - are circumvented by eco-friendly routes. The rationale behind this question is, that areas with high PM concentration should be avoided by vehicles, in order not to worsen the air quality in these particular areas. Eco-friendly routes are defined in this work as routes having low CO_2 emissions and low fuel consumption. The question will be answered using a test area in the city of Graz, Austria.

The paper is organized as follows. Section 2 lists the relevant literature, whereas section 3 elaborates on the methodology and the experiment conducted. The preliminary results are described in section 4, followed by a discussion and an outlook.

2 Relevant Literature

The relevant literature for CO_2 models, which are finally used for the eco-friendly routing approach. These models take into account a wide variety of factors. Pandian et al. [13] provide review of the key characteristics that affect the emission rates of a vehicle. These factors include road characteristics, traffic characteristics and vehicle characteristics. Road characteristics include, for example, traffic junctions or intersections. The traffic density or the queue length are among the traffic properties. Vehicle characteristics, such as vehicle age, fuel types or engine types, additionally affect CO_2 emissions. Fontaras et al.[8] provide another overview of the various factors that influence fuel consumption and CO_2 emissions of vehicles in Europe.

The air quality index in Europe is based on the Common Air Quality Index (CAQI), which was developed to compare air pollution in European cities. The index is divided into a roadside index and a background index, which are calculated hourly, daily and annually to make cities more comparable [17]. The CO_2 emissions are calculated using macroscopic, mesoscopic or microscopic models, depending on the level of detail required. The models used in this paper are based on [7, 21, 5].

Route planning with the help of real-time sensors is a topic, with a certain history in GIScience. Dynamic routing is mostly dealt with real-time traffic sensors and prediction [12, 15]. Other papers deal with real-time sensor that show obstacles that should be avoided - like forest fires [18]. Eco-friendly routing - the calculation of routes having a minimal CO_2 emission rate or fuel consumption - has been published by several authors in the last years [20, 4, 6]. Singleton [14] presented a GIS-based approach to model the CO_2 emissions of the commute related to pupils.

3 Methodology and Experiment

The methodology followed in this paper is based on an open road network dataset Graphen-integrationsplattform (GIP) [10], CO_2 and fuel consumption and emission models and air quality datasets for several time instants. The real-time sensor measurements provided by vehicles, are simulated with the help of real PM data - originating from the Province of Styria. The real-time sensor measurements are stored using an istSOS implementation [11] that is based on OGC standards [2, 1].

The method followed here evaluates 3 scenarios - where each scenario is a trip from a given start to an end point. We calculates three routes from start node to end node:

#1 shortest distance, #2 shortest travel time and #3 lowest fuel consumption. The fuel consumption is estimated using the spatial data of the GIP (average speed, slope, grade, road class, junction types, turn penalties, congestion), an standard diesel vehicle (EURO 6, 1500kg mass, cw value: 0.299, power: 93 kW) and the emission model PHEM [22]. In order to simulate the vehicle air quality measurements, we use PM data of the Province of Styria. The half-hourly average PM10 values of eight static measurement stations. An interpolated PM layer for the test area is calculated using the Inverse Distance Weighting method. In order to mimic floating vehicles (i.e. sensors), we distribute 10k vehicles randomly on the road network and let them report the PM value at their respective position using a OGC Sensor Web Enablement. These "synthetic" measurements are the basis for the eco-friendly route that circumvents areas with high air pollution.

In order to evaluate on the effect of the integration of real-time PM/air quality measurements, we compared the routes with and without the integration of PM/air quality measurements. In particular we analyzed the distances of each route segment to the centroid of the area showing PM10 values of 136-180 $\mu g/m^3$. The experiment is conducted in the City of Graz, using open governmental data on the road network [10]. Of the three routing scenarios with defined start and end nodes, we report on one particular scenario - because of length restrictions. The start point is Graz University of Technology, which is located in the south-east of the center of Graz, to a traditional Austrian wine tavern in the south west (district Wetzelsdorf).

4 Results

The results of the route calculations are described in this section. In particular the results of scenario 3 are discussed in detail here. The analysis of the effect of the integration of PM, we show the results of all three scenarios for one particular time instant.

The calculated routes of scenario 3 in the morning are identical to those for which no PM values have been taken into account (figure 1 - a). Due to the high PM values in the south and in the center of Graz in the evening, the routes at 18:00 and 18:30 show significantly different results. The PM hotspots will be bypassed at 18:00 in the north of the route according to distance and in the south according to the routes of time and fuel consumption. At 18:30 the all routes circumvent the high PM concentration in the north (see figure 1 - c & d). The bypassing of the high polluted areas at 18:00 causes a longer distance of around 3.5 km, a longer travel time of over 8 minutes and a fuel consumption of 0.19 l compared to the route without considering PM values. Further results for different time instants can be found in table 1.

The effect of particle matter on the routes is calculated by the average distance between each individual route and the respective centroids of the polluted areas (having highest PM concentration). The results of the scenarios depending on the optimisation parameters of the routes are shown for the time 18:00 in table 2. The average value of the line segments is calculated for each route and the routes with PM values and without PM values are compared at 18:00 (table 2). The average distance of the line segments and the routes considering PM values is greater than those routes not considering PM.

5 Discussion and Outlook

The paper has discussed question if real-time air quality vehicle sensor measurements have an effect on eco-friendly routes (low CO_2 emissions and fuel consumption), and avoid polluted

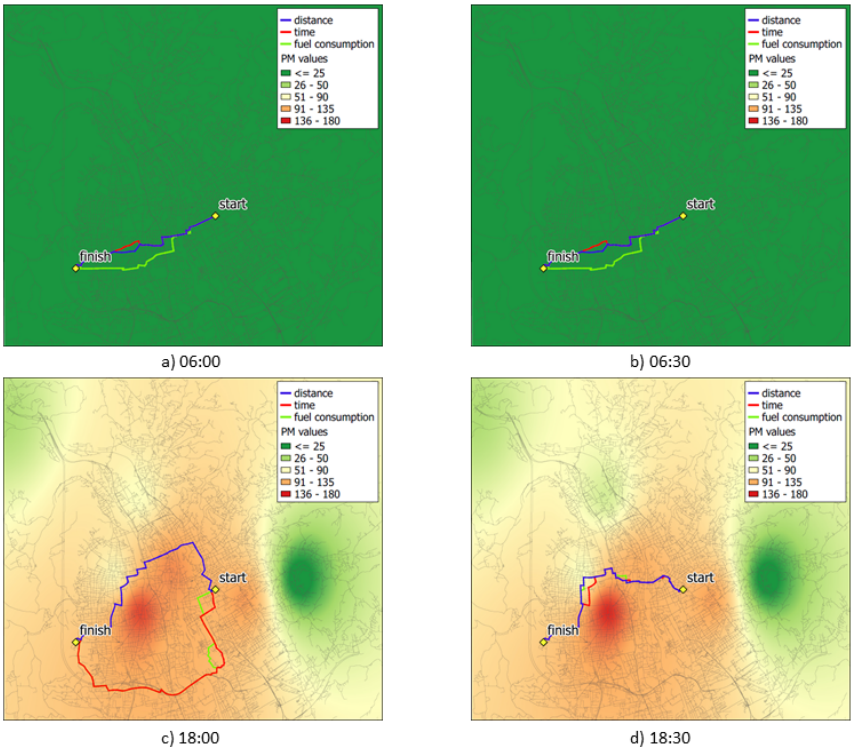

Figure 1 Presentation of the calculated routes with consideration of a high PM day (16.01.2019) at different times: a) 06:00 in the morning, b) 06:30 in the morning, c) 18:00 in the evening, d) 18:30 in the evening. The blue line denotes the shortest distance, the red line the shortest travel time, the green line, the route with the lowest fuel consumption. The underlying color (green to red) represents the PM values.

Table 1 Scenario 3 - Overview of the results of the individual routes. The routes without considering PM values concerning shortest distance (dis), time (time) and lowest fuel consumption (fuel) are given. The suffix "PM" denotes routes considering the PM values at the given time

Route	**Distance [km]**	**Time [min]**	**Fuel consumption [l]**	**CO2 [g]**
Dis - min	**6.40**	16.47	0.47	1262.65
Time - min	6.44	**16.35**	0.48	1266.01
Fuel - min	6.80	16.49	**0.46**	**1227.90**
DisPM 06:00 - min	**6.40**	16.47	0.47	1262.65
TimePM 06:00 - min	6.44	**16.35**	0.48	1266.01
FuelPM 06:00 - min	6.80	16.49	**0.46**	**1227.90**
DisPM 06:30 - min	**6.40**	16.47	0.47	1262.65
TimePM 06:30 - min	6.44	**16.35**	0.48	1266.01
FuelPM 06:30 - min	6.80	16.49	**0.46**	**1227.90**
DisPM 18:00 - min	**9.46**	**23.73**	0.71	1899.44
TimePM 18:00 - min	11.32	24.61	0.66	1756.89
FuelPM 18:00 - min	11.49	25.33	**0.65**	**1723.73**
DisPM 18:30 - min	8.44	21.13	0.58	1553.78
TimePM 18:30 - min	**8.34**	**20.20**	0.59	1581.77
FuelPM 18:30 - min	8.48	20.94	**0.57**	**1513.78**

Table 2 Average distance between PM centroids and line segments of the routes at 18:00 of each scenario. Columns dis, time, fuel represent the calculated routes concerning shortest **dist**ance, travel **time**, and lowest **fuel** consumption without considering PM detours and disPM, timePM, fuelPM consider circumventing the high PM areas.

Routes 18:00	dis [m]	disPM [m]	time [m]	timePM [m]	fuel [m]	fuelPM [m]
Scenario 1	1947.95	2274.01	1968.14	2431.10	2043.67	2297.95
Scenario 2	1537.07	1489.63	1295.74	1489.63	1388.60	1477.64
Scenario 3	1145.68	1218.51	1099.12	2552.57	1399.94	2588.44

areas? The question is evaluated based on a test area in the City of Graz, Austria. The preliminary results show that the integration of air pollution sensors from moving vehicles, may have an effect on the route suggestions - and could help to circumvent already polluted areas. In addition, such route suggestions could be made available for pedestrians and cyclists as well, as they are suffering most from poor air quality. Especially as vehicles are present in public roads, their built-in sensors could be utilized to sense the air quality in a city in real-time.

Currently, the algorithmic approach lacks a detailed analysis of the effect of the weighting of the different routing parameters - which have an effect on the route "choice" to avoid certain (polluted) areas. In addition, obtaining the location-based sensor measurements of cars is a complex legal problem - with ethical concerns on (geo-)privacy, security and confidentiality. In addition, the willingness of drivers to take a longer route to avoid areas of high pollution might be rather low. A motivational factor could be an incentive to lower a congestion charge/toll for the inner city when circumventing highly polluted areas.

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