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Development of a cloud-based service framework for energy conservation in a sustainable intelligent transportation system

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ABSTRACT

The research aims to develop a cloud-based service framework for reducing carbon dioxide emission and fuel consumption in intelligent transportation system. It collects traffic condition, driving behavior, and video through telematics and digital tachygraphy and road-side cameras to facilitate advanced data analytics for the reduction of fuel consumption. There are three specific features regarding this framework. First, a transportation cloud is built for the storage of massive data and video. This cloud-based system not only avoids the use of hard disks at client-site for energy conservation and reliability improvement, but also allows the back-end data analytics at both server and client sites. Second, a real-time traffic condition analytic was developed by mobile machine vision techniques based on video and data collected from road-side cameras to analyze and recognize traffic conditions, such as traffic flow, braking events, traffic lights, and count-down timers. Then, a fuel-efficient route navigation technology is also developed for eco-driving based on real time traffic information and a dynamic shortest path algorithm for saving time and fuel consumption. Third, a sequential pattern mining model was proposed to diagnose misguided driving behavior for eco-driving based on the real-time data collected from digital tachygraphy and on-board diagnostics system. Furthermore, an e-Learning visualization system was developed to provide advice and instruction for correction of misguided driving behavior. Indeed, the fuel consumption and power consumption can be reduced simultaneously based on the proposed framework regarding cloud-based system and eco-driving.

1. Introduction

Energy conservation and reduction of carbon dioxide (CO_2) emission have become important environmental issues for climate change (Sundarakani et al., 2010; Benjaafar et al., 2013; Li et al., 2013). Recently, CO_2 emission caused from burning fossil fuel has been a major part of greenhouse gas (GHGs) (Papagiannaki and Diakoulaki, 2009; Ando and Nishihori, 2011; Carrese et al., 2013; Demir et al., 2014). Total 28.1% energy consumption is from transportation which was shared 33.5% CO_2 emission in Unite State from fossil fuel consumption (Davis et al., 2013). The trend of CO_2 emission from automobiles is increasing (Kwon, 2005; Paravantis and Georgakellos, 2007; Ando and Nishihori, 2011) and need to develop advanced automobile with high fuel efficiency and carbon emission. The United State Environmental Protection Agency also presented that the most effective way to reduce CO_2 emission is reduction of fuel consumption such as by traveling in more fuel-efficient vehicle, using more renewable energy.

In practice, various advanced nations have been actively invested in telematics for the development of the Intelligent Transportation Systems (ITS) to reduce carbon emission (Grant-Muller and Usher, 2014). Telematics is a new-generation vehicle technology that integrates information, communications, and automotive electronics, and can be used for improving the travel efficiency, safety, and service life of vehicles. For example, dynamic navigation service in Japan showed that telematics is capable of achieving 20.3% savings in travel time, 25.8% increase in driving speed, and 17% reduction in CO_2 emissions. Experiments conducted in Beijing and Hanover indicated that traffic optimization using ITS probe vehicles could potentially reduce carbon emissions by 10–15%. Additionally, under the condition of 74.23% coverage and 85% accuracy in traffic information, experiments in Beijing measured a reduction of 18% in travel time. Furthermore, Nissan Motor Co. also showed that the

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installation of energy-saving auxiliary gauges in vehicles allows drivers to monitor speed and fuel consumptions at any time, and is estimated to help save 10–20% on fuel consumption, which is equivalent to a 320-kg annual reduction in carbon emissions (Barth and Boriboonsomsin, 2009).

Eco-driving is environmentally friendly used to not only reduce fuel consumption from automobile but also CO_2 emission. In eco-driving style, driver needs to simultaneously adjust the vehicle speed and accelerate the vehicle according to driving environment, determine the route decision by minimizing the fuel consumption (Young et al., 2011; Ando and Nishihori, 2011; Mensing et al., 2014). Indeed, the effectiveness of eco-driving in reduction of fuel consumption has been mentioned in many studies (Kato and Kobayashi, 2008; Beusen et al., 2009; Barkenbus 2010; Strömberg and Karlsson, 2013). Most studies regarding the eco-driving focus on shifting up as soon as possible, maintaining a steady speed close to the speed limit, and accelerating smoothly (Beusen et al., 2009; Andrieu and Pierre, 2012; Nie and Li, 2013), and anticipating traffic flow to mitigate stop-and-go motions (Manzie et al., 2007). However, it is difficult to maintain an eco-friendly speed while the vehicle locates in strict traffic congestion. Therefore, route selection affects the result of eco-driving and should be determined by anticipating the traffic conditions.

Driver navigation support tools which assist choice of travel route by the lowest fuel consumption instead of the smallest travel distance and time. Fuel consumption by optimization of trip route can be improved if real-time information of traffic conditions such as traffic lights, the number of vehicle stop, and traffic disturbance in the congested area are identified. Ericsson et al. (2006) used probe vehicles running in the street network to collect real-time traffic disturbance information for navigation. In order to provide real-time traffic conditions, the high density of probe vehicles should be required.

The accuracy of existing navigation services has increased significantly with continuous improvements in path algorithms. Given the rapid development of mobile devices such as vehicle data recorders and smart phones in recent years, the collection of sizeable and complete road traffic information is also gradually receiving more attention; traffic monitors installed at road intersections are able to capture large amounts of road and traffic information while automotive and navigation devices are also venturing into providing more diverse services such as fuel-saving navigation services. However, such services are still lacking in practical applications because they are subject to restrictions arising from the large amount of in-car data processing and analysis. The need for integrated capability in the in-car storage and processing of large amounts of road and traffic data is also rising rapidly with the development of cloud computing and big data analysis technologies. Cloud computing is a distributed parallel computing technology based on the internet, in which computing resources are virtualized before they are provided to users so that they are able to access a variety of integrated hardware and software services via the internet. Because cloud computing is capable of providing large amounts of high-capacity information storage and processing, it has led to a sharp increase in the amount of available information, as well as the need to provide timely value-added analysis services for large amounts of diverse data. With the development of cloud computing, in-car data recorders can also take advantage of improved scalability and availability of cloud-bases video storage systems.

Given the above, this research aims to propose a cloud-based service framework for sustainable transportation and reducing fuel consumption for the provision of the collection and storage of in-car video of traffic information as well the development of big data analysis methods and visual recognition technologies for mobile devices to provide fuel-efficient route navigation and eco-driving diagnostic services. We first use telematics and in-car data recorders for the collection of vehicle transportation information and leverage the data storage and processing capabilities of cloud computing to construct the transportation cloud-based service framework. Big data analysis technologies will be used to analyze large amounts of transportation data in the cloud-based system, such as smoothness of traffic, status of traffic lights and waiting times, so as to provide in-car fuel-efficient route navigation services. The proposed framework also conducts state analysis of fuel consumption against driving behavior and develops an eco-driving diagnostic system to identify improper driving behaviors and provide timely alerts, thereby improving these driving behaviors and promoting carbon emission reduction.

To construct a cloud-based service system, this research collects driving information from transportation vehicles, such as in-car traffic video, fuel consumption information, Global Positioning System (GPS) traffic information and traffic movement. The collection of traffic information in the past was largely done using fixed video surveillance systems/cameras such as closed-circuit television (CCTV), whereas today, it is mainly done with network video recorders (NVRs) using Internet protocol (IP) cameras, which has resulted in high storage costs given the huge amount of video data accumulated.

As to the storage of information, video data from cameras have traditionally been stored and processed using single-host or multi-server structures. Such structures can cause low utilization of computing resources and server load imbalance if used for recording huge amounts of video data from vehicle recorders, so that not only would the cost of maintenance be increased, it would also not be conducive for the analysis of in-car data. On the contrary, the visualization and cluster computing capabilities of cloud computing can bring a high degree of scalability and availability to storage systems. Compared with traditional practices, cloud computing is more advantageous in terms of the optimization of hardware resource utilization and load balance, as well as enhanced availability during sudden shut-downs.

In terms of fuel-efficient route navigation and driving behavior, big data analysis and mobile visual recognition technologies play an important role in the provision of in-car eco-driving information. The development of big data analysis technologies is crucial to the analysis and identification of useful in-car energy conservation information such as fuel-consumption analysis for different roads/road conditions, fuel-efficient route calculation and navigation, the relationship between driving behavior and fuel consumption, diagnostics for driving behavior, and alerts, from the huge amount of driving information collected by and stored in the cloud-based systems that often emerge in the form of streaming, and from a pool of factors that influence fuel consumption. However, the maturity and experience in the development of in-car telematics applications, such as energy conservation information services, road condition analysis, calculation of traffic flow, and location-based services (LBS) applications are still relatively lacking. In terms of in-car traffic analysis, complete traffic information collected from large number of users, including the smoothness of traffic, the status of traffic lights, and delays, is the basis for the identification of traffic conditions ahead, thus, the effective collection of in-car traffic information will facilitate the provision of a relatively good driving route for the driver. However, the existing studies mainly focus on in-car surveillance and the recording of car locations without considering traffic conditions. Also, conventional transportation information systems are limited to traffic information inquiry services and do not provide in-car traffic analysis. Furthermore, there has been little research and development on technologies relating to brake light detection, detection and