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Development of a wireless inspection and notification system with minimum monitoring hardware for real-time vehicle engine health inspection

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ABSTRACT

While many standards have been stipulated to control vehicular emissions, current inspection program for examining the engine health of in-use vehicles is practically ineffective and time-consuming. In particular, in-use vehicles are only required for inspection yearly, but huge amount of emissions may have been produced from malfunctioned engines daily. A new *wireless inspection and notification system* (WINS) is therefore proposed to monitor the vehicle engine health on the street *in situ*. The principle of WINS is to wirelessly examine some of the engine parameters through *radio frequency identification* (RFID) and traffic lights. RFID tags are installed on vehicles to collect the engine health information, whereas RFID interrogators are installed on traffic lights for wireless data transmission. Experiments were carried out to evaluate the effectiveness of the proposed WINS, and the results show that the proposed WINS is more convenient and economical than traditional vehicle inspection system. Moreover, as there are more than hundreds of traffic lights in the traffic network of a city, a *maximum spanning tree* (MAXST) algorithm is proposed to determine the suitable number of RFID devices required in the network so that the implementation cost, system loading and missing rate can be optimized. Different from the typical spanning tree algorithm in operational research, the MAXST algorithm has a domain-specific rule and weight calculation method for this application. To verify the methodology, simulations on the traffic networks of Shenzhen, New York and London were conducted. Results show that only 25–40% of traffic lights of the traffic networks are necessary for installation of RFID interrogators, with a rate of 2–7% that the vehicle owners may be able to escape the location of RFID interrogators.

1. Introduction

Vehicular emissions are the dominant source of urban air pollutants. Many metropolises are suffering from severe air pollution problem due to the growing number of on-road vehicles. In some regions, the air quality has even reached levels judged as hazardous to human health (Gong et al., 2012; Kan et al., 2012; Zhang and Batterman, 2013). To regulate the amount of vehicular emissions, increasingly stringent emission standards have been established and promoted in major developed countries. These standards basically define limit values for the level of exhaust pollutants of in-use vehicles.

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In fact, to reduce the exhaust pollutants, the three-way catalytic converter has been widely adopted on modern gasoline vehicles. Yet the efficiency of the three-way catalytic converter is strongly affected by the engine air–fuel ratio, or *lambda* (λ, normalized air–fuel ratio), as shown in Fig. 1 (Faiz et al., 1996). It can be seen that derivation of only 1% from the stoichiometric λ value can result in significant degradation on the conversion efficiency (Heywood, 1988; Faiz et al., 1996; Wong et al., 2015). Therefore, in many major cities in Europe and Asia, λ has been included as an examination index in their local in-use vehicle emission standards for catalyst-equipped gasoline vehicles (e.g., in United Kingdom and Hong Kong, λ is limited to 1 ± 0.03 at high idle speed (Anon., 2014)). The main purpose is to examine the performance of the mixture system, and the functionality of the three-way catalytic converter.

In general, all in-use vehicles must be examined periodically to check if they are in compliance with the emission standards. Vehicles that fail the emission tests must be repaired and re-inspected before registration renewal. The effectiveness of the vehicle inspection procedure, however, has been criticized for years (Harrington et al., 2000; Kazopoulo et al., 2007; Rhys-Tyler et al., 2011). Since this vehicle inspection is a relatively expensive and time-consuming procedure, it is practically impossible for the authority to inspect every vehicle daily or monthly, but annually or biannually after 6–10 years of car registration. Thus, the vehicle owners only need to fulfill the requirement of the scheduled inspections at their least cost without improving the conditions of their in-use vehicles/engines (Bin, 2003); they might purchase cheap parts that can temporarily improve the engine health conditions, and ignore further durable repairs once the tests are passed due to their lack of self-regulation. Moreover, some studies (Ropkins et al., 2009; Carslaw et al., 2011; Chen and Borken-Kleefeld, 2014) already indicated that the actual on-road vehicular emissions are usually much higher than those measured during the mandatory vehicle inspections. In other words, the authority is unable to acquire and control the on-road emission status of the vehicles and improve the urban air pollution. Although remote sensing has been employed for non-scheduled on-road inspections (Bishop and Stedman, 2008), it still potentially suffers from the problems that the vehicle owners may adjust the level of the tailpipes so that the remote sensors could not measure the emissions well, or make the license plates difficult to read so that the authority could not identify the vehicles as the remote sensing takes measurements under less controlled conditions (Hubbard, 1997).

From this viewpoint, a new effective wireless inspection and notification system (WINS) for real-time on-road vehicle engine health inspection is proposed in this study. The idea of WINS is to acquire *in situ* some of the engine health indicators (e.g., air–fuel ratio, emissions level) via wireless technology. Provided that all vehicles are attached with specially designed communication devices, their engine health information can be wirelessly transferred to a backend system. From the backend system, the authority can then precisely and rapidly judge which vehicle is suspected of failing the local emission standard, followed promptly by sending out notices (e.g., SMS or emails) to the owners for vehicle repair. With WINS, the authority can also easily and automatically check the on-road vehicle license numbers without physically reading of the license plates, making it more difficult for the vehicles owners to avoid the inspection.

Obviously, the core of WINS is the communication device. Among different wireless communication techniques (Yan et al., 2008; Bottero et al., 2013; Mahmood et al., 2015), radio frequency identification (RFID) is a low-cost and mature one that enables objects to communicate with others using radio frequency and has recently been utilized in different transportation systems (Qiao et al., 2014; Wang et al., 2014). The two components of RFID technology, namely RFID tag and RFID interrogator, perfectly match the requirement of WINS. By attaching the RFID tag on a vehicle, the information from the vehicle sensors can be easily acquired. The RFID interrogator can then act as the on-road monitoring device to communicate with the RFID tag, and forward all relevant information to the backend system for further processing. Therefore, RFID is a reasonable choice to implement WINS.

Nevertheless, a noticeable problem for WINS is that, where the RFID interrogators should be installed. Like other traffic monitoring systems, the effectiveness of the WINS depends strongly on the rational selection of the monitoring locations

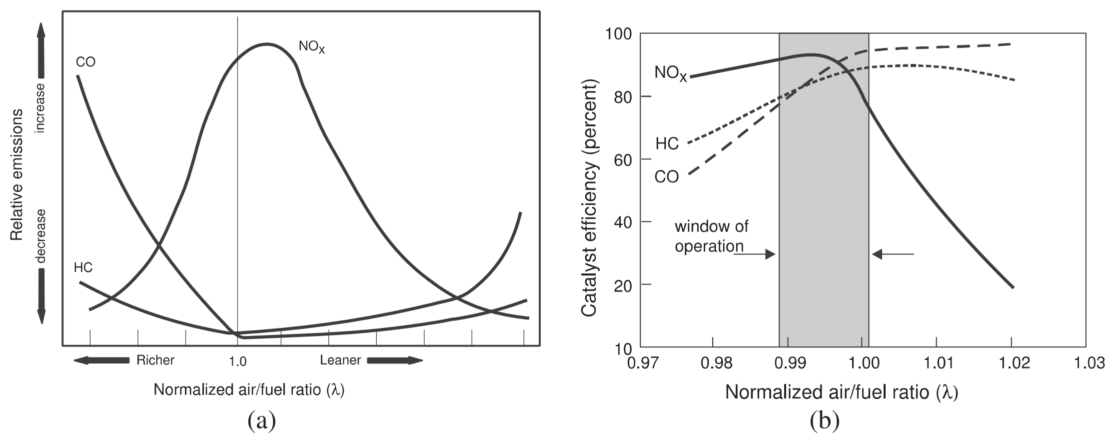

Fig. 1. Effect of λ on (a) gasoline engine emissions, and (b) three-way catalyst converter (Faiz et al., 1996).