Transportation Research Part D 48 (2016) 161–170

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Categorisation for air quality assessment in car cabin

Andrzej Szczurek, Monika Maciejewska *

Faculty of Environmental Engineering, Wroclaw University of Technology, Wybrzeże Wyspianskiego 27, 50-370 Wroclaw, Poland

ARTICLE INFO

Article history:
Available online 20 August 2016

Keywords:
Indoor air quality
Sensor
Category
Car
Information
Entropy

ABSTRACT

The objective of this work was to propose a way of preparing information about in-cabin air quality for the car driver or passenger. It was assumed that information should be objective, relevant, current, complete and useful. The major elements of our concept were: (1) monitoring of selected air parameters inside the cabin, (2) determination of indicators that characterise indoor air, based on measurements, and (3) the method of information extraction. We proposed to realise the first task with a sensor system. The second and third goals were reached by categorisation. The basis for defining categories were ranges of values of measured parameters or their combinations. In a way, the categories were used to quantify indicators of air quality. Shannon entropy and mutual information were applied to find the best categorisation. The concept was investigated using experimental data from car cabin air monitoring in various driving conditions. We conclude that information about air quality in car cabins may be successfully conveyed using the following indicators: *thermal conditions* – determined based on temperature and relative humidity measurements; *air exchange* – determined based on CO_2 concentration; and *air freshness* – determined based on volatile organic compounds (VOCs) content in car cabin air. Each indicator has three categories: bad, intermediate and good.

1. Introduction

The interior of a vehicle is regarded as a specific microenvironment. It is mainly experienced via air quality, thermal conditions, noise levels and vibration. Air quality (AQ) is a term that describes the physical, chemical and biological state of indoor air at some place and time. Usually, it is characterised by physical and chemical parameters such as temperature (T), relative humidity (RH), airflows (Musat and Helerea, 2009), and the concentration of specified pollutants (Riediker et al., 2003).

A system for providing comfortable conditions in the cabin is a key component of automobiles. Climate control devices were first introduced into cars in the early 1960s and are available in many vehicles today. They can consist of controlled ventilation, heater and air conditioner. A combination of heating and air conditioning is a standard in most vehicles for temperature control. Climate control systems are also used to regulate fan speed and air circulation. They prevent polluted air and toxic gases from entering the car cabin. Some vehicles have extra devices, such as humidity controls and clean-air systems, with integrated high-efficiency air filters and ionising air cleaners. Many automobiles incorporate solar-control glass to reduce solar transmission to the car cabin. Today's climate control systems have a positive influence on the comfort, safety and health of drivers as well as passengers (Grady et al., 2013).

* Corresponding author.
E-mail address: monika.maciejewska@pwr.edu.pl (M. Maciejewska).

http://dx.doi.org/10.1016/j.trd.2016.08.015
1361-9209/

In climate control systems, a method of air quality evaluation plays an important role. Two strategies are used to obtain information about the parameters describing air quality. The oldest approach is based on stimuli that come from the environment and are perceived by human senses. This method is simple and cheap. Unfortunately, the human senses pose a number of problems when used as a source of information. Perception of physical and chemical conditions alters over time and varies among people. It is prone to bias, fatigue as well as attention drift (Cheng et al., 2006a,b; Gladyszewska-Fiedoruk, 2011).

Much more reliable information is obtained if measuring systems are applied (Cheng et al., 2006a,b; Tan et al., 2006). Usually, they are based on sensors of appropriate air parameters and a computer that regulates the entire air exchange system in the vehicle cabin (Galatsi and Wlodarski, 2006; Ramya and Palaniappan, 2012). Car evolution and progress in sensor technology have led to around 10% of produced cars now being equipped with Air Quality Sensors (AQS). These devices are crucial for measuring physical quantities required for heating, ventilation and air conditioning (HVAC) control units, to adjust its settings. Sensors are also used to detect undesired gases and odours outside as well as inside the car (Blaschke et al., 2006), automatically triggering actuators to adjust the flow of air into and out of the cabin. They are an effective protection against all common traffic exhaust gases: carbon monoxide (CO) and hydrocarbons (HCs) – typically produced by gasoline engines; nitrogen oxides (NOx) – produced by diesel engines; as well as a wide variety of volatile organic compounds (VOCs: Fedoruk and Kerger, 2003), which may cause smells. Sensor systems offer the ability to monitor various parameters without manual intervention.

The key issue in an air quality control is a form of information provided by a measuring system (Nakagawa et al., 2000). In practice, it is determined by air quality evaluation. Information generated by the measuring system is first of all used for the automatic adjustment of indoor air parameters. In this case, the measuring system outputs are calculated using relative changes of individual sensor responses compared to a moving average reference. On this basis, the ventilation, heating and cooling are appropriately adjusted and the climate control system determines how to maintain the strictly selected conditions (Chung and Lee, 2008). In order to perform this operation, settings defined by the driver through the computer system are required. Information generated for the automatic control of air quality is of key importance for car driving. In this way, drivers are not forced to move the controls for adjusting parameters of indoor air constantly.

However, the increasing awareness of the strong influence of car microenvironment on drivers and passengers leads to automobile users also being interested in the provision of actual and comprehensive characteristics of air inside the car cabin, for their own knowledge. In this case, it is assumed that air quality evaluation should be performed quickly (i.e. in real-time), on-site, and should result in concise, easy to absorb information. Unfortunately, the outputs of a measuring system cannot be directly used for comprehensive description of air quality (Szczurek and Maciejewska, 2015). On the other hand, multivariate analysis of sensor data requires some knowledge and cannot be performed by drivers during a trip. Their involvement in this process might elevate the likelihood of collision or other road fatalities.

The aim of this work is to show that an automatic, multi-sensor system and data categorisation algorithm can provide the driver and passengers with comprehensive information about in-cabin air quality.

2. Methodology

2.1. Assumptions

At the foundation of our approach lies the measurement method. We consider measurements as a source of data that are the basis for preparing information about air quality in car cabins. It was assumed that the quantities measured should correspond to major aspects of air quality in car cabin. Based on the experience that has been accumulated in the domain of indoor air quality assessment, we chose to consider the following parameters: air temperature, relative humidity, CO_2 concentration and VOCs content in the air. Temperature, as well as humidity, is relevant for the evaluation of thermo-humid conditions. CO_2 concentration and VOCs content are associated with the chemical aspect of air quality. We assumed that the measured values of these parameters form the basis for extracting information about air quality in car cabins.

There is a number of ways in which the measurement data may be utilised for preparing information. The choice of the most adequate one is largely influenced by the recipient's ability to retrieve information. In the case of a car driver, this problem is very important. In driving conditions, any messages on side issues have to be concise and easy to absorb, while high information content is maintained at the same time.

As a primary solution, one could consider informing the driver about measured air parameters directly, without any processing. This option is relatively simple to realise, but at least two important arguments against the proposal must be weighed. First, it could be anticipated that the average car user is unprepared to establish the link between the values of various measured parameters and air quality. As a consequence, the data presented would be useless for him/her. The second argument is related to the number of quantities. We think that processing the information contained in the time series of dynamically changing values may require too much mental power if the number of parameters is excessive. Namely, a driver offered too many air parameters to follow at the same time may give up tracing any of them.

Still, we have proposed and discussed an indirect approach that involves multivariate measurement data processing for information extraction. The key element of this approach is categorisation. We considered two ways of performing categorisation: individual and combined. The first consisted of specifying categories for individual measured parameters of car cabin