ELSEVIER

Automation in Construction 17 (2008) 130 – 136

AUTOMATION IN CONSTRUCTION

www.elsevier.com/locate/autcon

GA-based fuzzy controller design for tunnel ventilation systems

Baeksuk Chu [a], Dongnam Kim [a], Daehie Hong [b,*], Jooyoung Park [c], Jin Taek Chung [b], Jae-Hun Chung [d], Tae-Hyung Kim [e]

[a] *Graduate School, Department of Mechanical Engineering, Korea University, 5-1, Anam-dong, Sungbuk-gu, Seoul, 136-701, South Korea*

[b] *Department of Mechanical Engineering, Korea University, 5-1, Anam-dong, Sungbuk-gu, Seoul, 136-701, South Korea*

[c] *Department of Control and Instrumentation Engineering, Korea University Jochiwon, Chungnam, 339-700, South Korea*

[d] *Department of Mechanical Engineering, Stevens Institute of Tech., Castle Point on Hudson, Hoboken, NJ 07030, USA*

[e] *Fire and Engineering Services Research Department, Korea Institute of Construction Technology, Kyunggi-do, 411-712, South Korea*

Abstract

The main purpose of a tunnel ventilation system is to maintain CO pollutant concentration and visibility index (VI) under an adequate level to provide drivers with a comfortable and safe driving environment. Moreover, it is necessary to minimize power consumption used to operate the ventilation system. To achieve the objectives, fuzzy control (FLC) methods have been usually utilized due to the complex and nonlinear behavior of the system. The membership functions of the FLC consist of the inputs such as the pollutant level inside the tunnel, the pollutant emitted from passing vehicles, and the output such as the number of running jet-fans. Conventional fuzzy control methods rely on simple experiences and trial and error methods. In this paper, the FLC was optimally redesigned using the genetic algorithm (GA), which is a stochastic global search method. In the process of constructing the objective function of GA, two objectives listed above were included: maintaining an adequate level of the pollutants and minimizing power consumption. The results of extensive simulations performed with real data collected from existing tunnel ventilation system are provided in this paper. It was demonstrated that with the developed controller, the pollutant level inside the tunnel was well maintained near the allowable limit and the energy efficiency was improved compared to conventional control schemes.

Keywords: Tunnel ventilation control; Fuzzy logic controller (FLC); Real-valued genetic algorithm (GA)

1. Introduction

An appropriate operating of a roadway tunnel ventilation system provides the drivers passing through the tunnel with a comfortable environment and safe driving conditions. However, the tunnel ventilation system consumes a large amount of energy. Hence, it is desired to have an efficient operating algorithm for the tunnel ventilation in the aspects of a safe and comfortable driving environment as well as energy saving. The main target of the roadway tunnel ventilation is to maintain CO pollutant and visibility index (VI) to a certain level. CO pollutant is mainly emitted from gasoline-powered passenger cars. The amount of CO pollutant over an allowable level may cause fatal injury to human body. Generally, 100 ppm is the maximum CO limit that can be allowed [1]. VI is mainly decreased by the smoke emitted from diesel buses and trucks. The low VI may considerably decrease the safety of the drivers due to the poor visibility, which may lead to traffic accidents.

The pollutants in the tunnel are exhausted from passing vehicles, which are the moving sources. Moreover, their transient behavior is characterized with a time delay. Such complex and nonlinear characteristics make it difficult to control the ventilation system with conventional quantitative methods. In this respect, the most popular control method for the ventilation systems has been fuzzy logic control. There have been many studies for tunnel ventilation control using fuzzy logic. Tunnel ventilation control system using artificial intelligence was introduced [2] and various experiments on tunnel ventilation control were conducted [3]. Fuzzy model based control scheme was devised [4] and lots of ventilation techniques using fuzzy logic were designed thereafter [5,6]. Saving energy effect by road tunnel ventilation control system was also researched [7]. Moreover, there was a study for evaluating the efficiency of tunnel ventilation controller, using a class of performance index [1]. Recently, a very accurate pollution level estimation algorithm for tunnel system utilizing Kalman

* Corresponding author. Tel.: +82 2 3290 3369; fax: +82 2 926 9290.
E-mail address: dhhong@korea.ac.kr (D. Hong).

0926-5805/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.autcon.2007.05.011

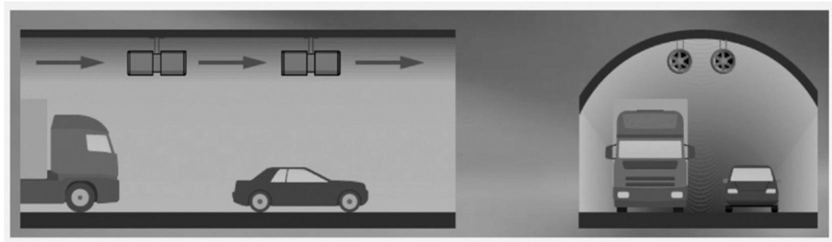

Fig. 1. Schematic diagram of Dunnae tunnel with jet-fans.

filter was designed [8]. The estimated information can be used to develop more efficient control methods for tunnel ventilation.

In this paper, a systematic method for generating membership functions is pursued for optimal fuzzy logic control based on the genetic algorithm (GA). Two main considerations are translated into the objective function for the GA, which include the pollutant concentration level and energy efficiency. A GA-based fuzzy controller is designed to optimally satisfy the objectives.

This paper is organized as follows. In Section 2, the target system for this research is briefly introduced. In Section 3, a conventional fuzzy logic control method is described. Section 4 presents how FLC can be improved by GA. The simulation results are discussed in Section 5, which is followed by some concluding remarks in the last section.

2. Tunnel ventilation system

The Dunnae Tunnel located on Youngdong highway in Korea was selected as the target system for this study. Fig. 1 and Table 1 show a schematic diagram and detailed specifications of the tunnel, respectively. To observe the pollutant levels, CO and VI sensors were installed inside the tunnel in an appropriate interval. The traffic counter located at the tunnel entrance records the number of cars entering the tunnel. In order to ventilate the pollutants, a total of 32 jet-fans were installed on the ceiling.

The distribution of the pollutants inside the tunnel is usually expressed as a one-dimensional diffusion-advection equation [4],

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial c}{\partial x}\right) - V_{\mathrm{w}}\frac{\partial c}{\partial x} + q \tag{1}$$

where c is the pollutant concentration, V_{w} is the wind velocity and k is the diffusion coefficient. The first term on the right-hand side explains the diffusion of the pollutants and the second term does the advection by wind. The pollutant source q increases the pollutant level inside the tunnel. However, because the advection and source terms generally dominate the pollutant distribution, the diffusion term is often ignored. Then, the one-dimensional advection equation can be rewritten as

$$\frac{\partial c}{\partial t} = -V_{\mathrm{w}}\frac{\partial c}{\partial x} + q \tag{2}$$

In order to estimate the change in pollutant distribution, it is necessary to identify the wind velocity inside the tunnel. It can be calculated by the force balance equation, which is expressed as

$$\begin{aligned} &\rho AL\frac{\mathrm{d}V_{\mathrm{w}}}{\mathrm{d}t} = \sum F \\ &\sum F = F_t + F_j + F_r + F_n \end{aligned} \tag{3}$$

where $\sum F$ is the summation of the forces that affect the wind in its flow velocity inside the tunnel [9]. F_t is the traffic ventilation force by passing vehicles, F_j is the equipment ventilation force by jet-fan operation, F_r denotes the wall friction resistance and fluent loss at the entrance and exit, and F_n explains the wind resistance by the natural wind outside the tunnel. Besides, ρ is the density of air, A is the cross-sectional area of the tunnel, and L is the longitudinal length of the tunnel.

Table 1
Specifications of Dunnae tunnel

Tunnel	Dunnae
Length	3300 m
Width	9.2 m
Height	7.2 m
Lane	2
Cross-sectional area	65.65 m^2
Ventilation	Jet-fan type

3. Fuzzy logic controller (FLC)

The fuzzy logic controller applied to the tunnel ventilation system is composed of three parts as follows.

— Fuzzification: transformation of the input data, pollutant level, and pollutant emission rate to a linguistic form.
— Inference: generation of a fuzzy control input based on fuzzy relations and inference rules.
— Defuzzification: convertion of fuzzy values induced in the inference into crisp defuzzified values.

3.1. Fuzzification

The FLC inputs include the CO pollutant level, VI, and pollutant emission rate to be measured. In this paper, only the CO level and pollutant emission rates are considered in the controller design. It is noted that adding a VI level to the control algorithm is quite straightforward. The output of the FLC is an