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Fuzzy-controlled tunnel ventilation system

S. Kohno [a] and Y. Kikuchi [b]

[a] Manager, Ph.D., Civil Engr. Div., Shimizu Corp., No.2-3, Shibaura 1-chome, Minato-ku, Tokyo 105-07, Japan

[b] Deputy General Manager, Civil Engr. Div., Shimizu Corp., Shimizu Corp., No.2-3, Shibaura 1-chome, Minato-ku, Tokyo 105-07, Japan

Abstract

The working condition inside the tunnel under construction is badly affected by the occurrences of the dust, CO and NOx due to the blasting, shotcreting and moving vehicles. Also, hot and humid conditions may be found at the excavation face being caused by the heat from the machines and ground. The authors have developed a fuzzy-controlled ventilation system for improving the working conditions. The paper reports its validities based upon the actual data and observations.

1. INTRODUCTION

Due to the increase in demand for underground developments, tunnel technologies are becoming very important. In excavating rock ground, it is very common for methods using blasting and concrete spraying (Shotcrete) to be employed. This method is called the New Austrian Tunnelling Method (NATM).

Though use of blasting may largely increase the advance of the excavation with lower cost compared with that by machines such as road header, it can degrade the environment inside the tunnel by generating harmful by-products such as CO and dust. Shotcrete also generates the high density of dust, even though the spraying technologies have been well developed. After blasting, several machines are used in mucking and transporting the waste, and NOx and CO are generated. During the drilling of the bore holes, it can be common that dust is not generated so much but the working conditions are badly degraded by the high temperature and humidity from the ground. Under those circumstances, ventilation systems are needed.

Conventional ventilation systems, still widely used, run with constant fan speed. When its speed is manually fixed at a high rate, the working environment is always clean. However, such fans run at high speed even when the working circumstances are already clean and it is therefore not economically efficient. On the contrary, the low speed of fan may not sufficiently improve the working condition when a fan is actually required.

Recently, to solve such problem, a fan has been invented so that its speed can be changed in three steps, that is low, medium and high corresponding to the dust density. The efficiency has been largely improved. However, it may not be operated for the case of high temperature and humidity under low dust density conditions.

Construction industries are facing the labour shortage problem caused by its unpopularity among young engineers, ageing of the workers and shortage of the skilled workers. Also, social interests have started being placed upon the environmental aspects of the work and accordingly demanding improvements in the working conditions. It is important that ventilation systems are introduced to maintain the good working conditions for the workers, regardless the working procedures and surrounding conditions and thus help to activate the construction industry.

This paper introduces a newly invented ventilation system which operates taking into account the improvement of comfortability in addition to the removal of the harmful things. Its validity is discussed.

2. OUTLINE OF SYSTEM

In selecting the items observed to determine the fan speed, they are considered in two categories, which are categories corresponding to the harmful things and that relate to comfortability.

For the items selected. for the first category are dust density and CO density. NOx density was originally included. However, since current NOx sensor is too large to be easily transported and also that it is reported that NOx is well correlated with CO density, Nox is removed of the items directly affecting the fan speed. However, Nox density is periodically observed at the site and its effect upon the environment is always monitored. Also, this system is designed to incorporate the effect of NOx when an easily movable sensor is introduced in the near future.

In determining the items for the second category, working conditions at 12 tunnel project sites have been examined in terms of what items could badly affect comfortability. The outcome of this is that temperature and humidity are considered to be the two most important items.

The purpose of the system is to eliminate undesirable working conditions and recover a good environment as soon as possible though operating a fan based upon the observed CO and dust densities, temperature and humidity on a real-time basis. The system configuration is shown in the Fig.1: System Configuration. The system consists of the two fans, sensors, control units and a personal computer. A supplementary fan blows the contaminated air toward the excavation face and such air can be blown out of the tunnel by the main fan. The number and configuration of fans will depend upon the tunnel size and construction procedure and proposed technique and may be adopted to any configuration. In this case, it is designed that working conditions near excavation face should be mostly kept good and accordingly, sensors are positioned there. It is always the case that working condition at the excavation face are badly degraded and its improvement is desired. The monitored values at the sensors are transmitted by means of cables to a personal computer based in the office. Also, the current speed of the fan is always observed at the sensors located inside the fans and this information goes to the computer. At the computer, based upon this information, the desirable fan speed is obtained by calculating the value of speed change to the current one and commanded to the fans through control units.

In determining the desired fan speed, fuzzy theory ([1],[2]and [3])is used on account of the following advantages:

(1)Since at least four observed items are simultaneously inputted into the computer for determining the fan speed, the usual mathematical approaches may require a complicated calculation procedure resulting in control delay and need for a more powerful computer than a personal computer.

(2)How the human being feels may not be properly identified by the usual mathematical procedures.

(3)In adjusting the applicability of the system following its introduction, a fuzzy-aided system can be easily tuned without remodelling the system which might be necessary with the mathematical approach.

Fuzzy theory was first presented by Prof.L.A.Zadeh in 1964 and is widely applied in Japan in control fields such as auto-driving of the shield machines and subways.

3. DETERMINATION OF FAN SPEED

The degrees of each items to be input and output, which are dust and CO densities, temperature, humidity and speed change of fan are usually represented by the workers using such terms as "too hot" and "very clean". These degrees are too ambiguous in definition and numerical interpretation may cause some error besides the difficulties in procedures. Therefore, in this system, these item are represented using the fuzzy sets. Their membership functions are shown in Fig. 2 : Fuzzy Set (CO Density) and Fig. 3 : Fuzzy Set (Fan Speed Change), for examples.

Based upon these items, the procedure to obtain the desirable fan speed is shown in Fig.4. The harmful things such as dust should not be treated together with comfortability items such as humidity, since the former one could directly harm the human body while latter ones just what improve the working conditions. Consequently, harmful things and comfortability items are analysed separately and corresponding values of speed changes calculated. DY1 and DY2 are obtained using fuzzy inference procedures referring to a predetermined database. This database involves several rules consisting of the condition parts and conclusion parts in relating the input with output. An example rule in terms of the dust and CO densities is "If dust density is very high and CO density is low, then the increase in fan speed change DY1 is very large". These rules are based upon the opinions of experts and theoretical relationships.

The calculated speed changes, DY1 and DY2 are combined together generating a single value of speed change, DY by weight factor, α. This is a weighting for DY1 and accordingly, (1- a) is a weight to DY2. α is not a constant value and it can be determined to correspond to the degrees of the occurrence of the harmful things and comfortability. For example, when degree of the harmful things is observed to be more serious than that for comfortability, α is automatically large and a high weight is applied to DY1. The calculation of α is also performed by fuzzy inference based on the four observed items referring to the pre-determined rules. Rules are determined so that when temperature and humidity are below the expected values, the removal of the harmful things has a high priority and when any of these exceed the expected values, improvement of the comfortability can start being accounted for. Consequently, large α means the ventilation placing a large weight on the removal of the harmful things while small α is found when the working area is very uncomfortable.

Finally, the calculated DY is added to the current fan speed and thus the desirable fan speed Y is evaluated.

4. APPLICATIONS

This system has been introduced into three tunnel project sites as shown in Table 1. The cross-sectional area of those tunnels are $70m^2$ through $100m^2$, and their lengths exceed 1000m. Maintaining satisfactory working conditions at the working area near the excavation face is placed at a high priority. The configuration of these fans, which have been introduced at the three sites, is shown in Fig.1. Photo 1: View of System. shows a view of the two fans with the control unit at the centre. Sensors are shown in Photo 2 : Sensors, and their size is less than 30cm x 30cm. They are light weight and can be easily moved.

Table 1. Tunnels using System

Name of Tunnel	Cross-Sectional Area (m^2)	Length (m)	Purpose
Asahi	100	1800	Maglev Train
Torimatsuyama	80	1110	Road (Toll way)
San-nohe	70	4250	Bullet Train

The working conditions represented by dust and CO densities, temperature and humidity and the corresponding fan speeds are monitored on a real-time basis using the personal computer at the office, as shown in Photo 3 : Monitored Screen. Whether speed is decreasing and whether removal of the harmful things is more weighted can be easily understood by the bar charts shown on the top of the screen.

Fig.5 shows a transition of the fan speed with time responding to changes in the dust density, CO density, temperature and humidity. The point where CO density jumps up denotes the blasting, and it is observed that the fan speed also jumps up. After blasting, mucking starts and high density of dust is generated. During this working stage, the fan still runs at the maximum speed. When mucking is finished, around 2 o'clock, and dust density decreases and the fan speed is reduced until the shotcrete starts, this generating a high density of dust. As can be understood from figure 5, the fan speed easily changes in response to changes in the working conditions. Thus, the efficiency and validity of the system are observed.

In terms of the effects of the temperature and humidity on the fan speed, they may not change largely within a day and their effects may not be easily examined. However, it is often reported at those tunnel sites using this system that the fan keeps blowing with a high speed during drilling work at the excavation face with low density of harmful things under a very humid condition. It is also observed that fan stops early in the morning and starts blowing with the increase of temperature even when there is no work on such day. After the introduction of this system, the occurrence of foggy conditions inside the tunnel, due to the high humidity, may not be seen even though this is particularly common in spring through to early summer.

All the monitored data about working circumstances are automatically stored on the hard disk of the computer and statistical methods can be used to analyse trends. Also, transitions in the observed items are automatically listed according to directed formats. This data could be very important for future planning of ventilation systems.

The validities of the system are sufficiently confirmed through use at three sites and they are summarised as follows:

(1)When the working conditions are degraded, the fan runs at a high speed and rapidly recovers a comfortable environment.

(2)The fan speed decreases along with the improvement in the working circumstances and thus its operation is efficient.

CONCLUSION

For the purpose of improving the working conditions, a newly developed ventilation system is presented in this paper. This system is working in three tunnel project sites and its validity has been highly evaluated by the site engineers and workers. It may largely contribute to the overall improvement of the working conditions at the project sites and contribute to the recovery of the popularity of the construction industry among young engineers. The system originally developed for the tunnel construction may be easily applied into the other fields, such as subways and building constructions. Further introductions of the system will be attempted and the additional data accumulated will become absolutely indispensable.

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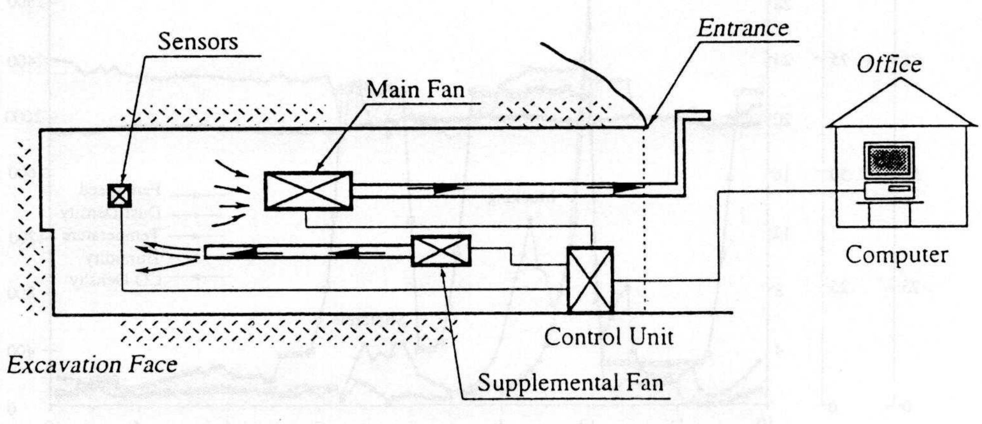
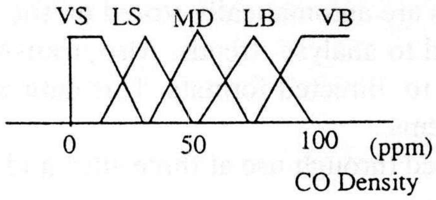
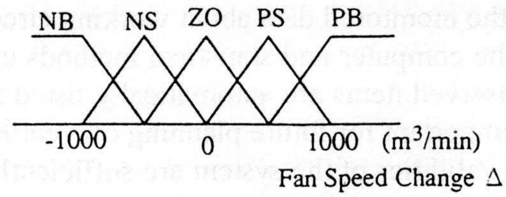


Fig. 1 : System Configuration



VS : Very Small
LS: Liitle Small
MD: Medium
LB: Little Big
VB: Very Big

Fig.2. Fuzzy Set (CO Density)



NB: Negative Big Largely Decrease
NS: Negative Small Decrease a little
ZO: Zero Maintain
PS: Positive Small Increase a little
PB: Positive Big Largely Increase

Fig.3. Fuzzy Set (Fan Speed Change)

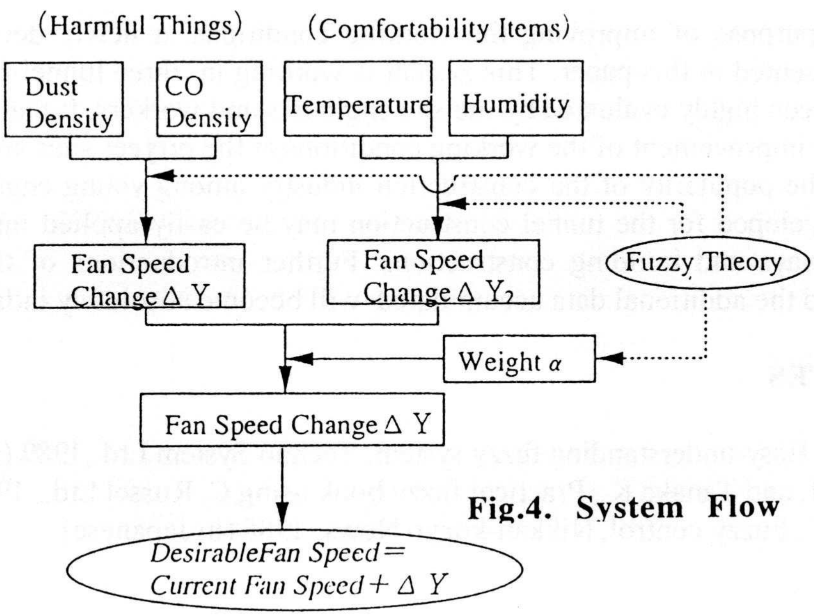


Fig.4. System Flow

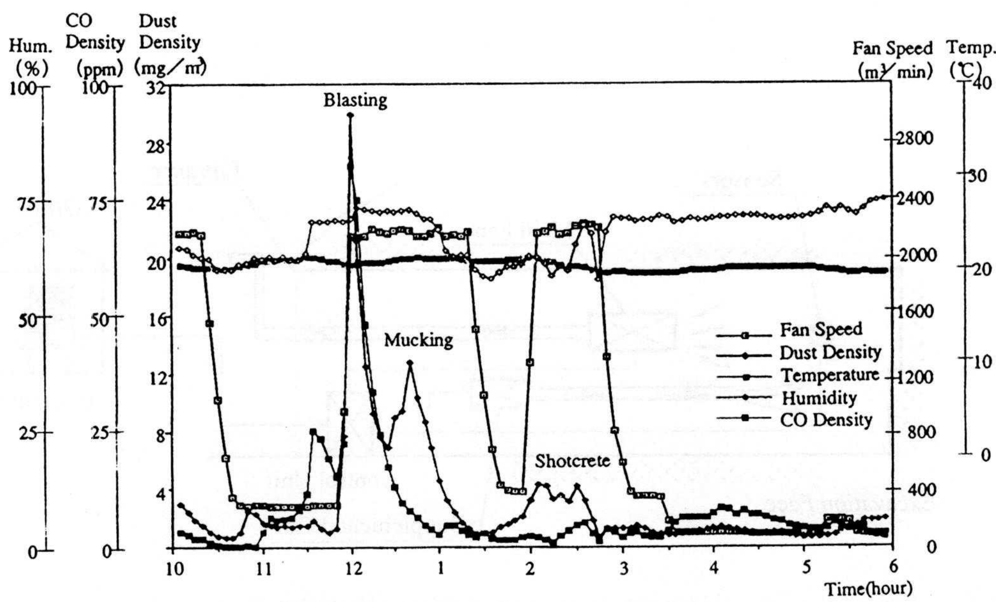


Fig.5. Transition of Fan Speed and Working Condition

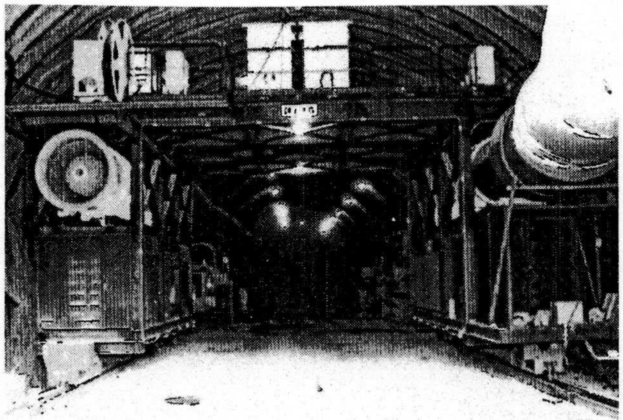


Photo 1. View of System

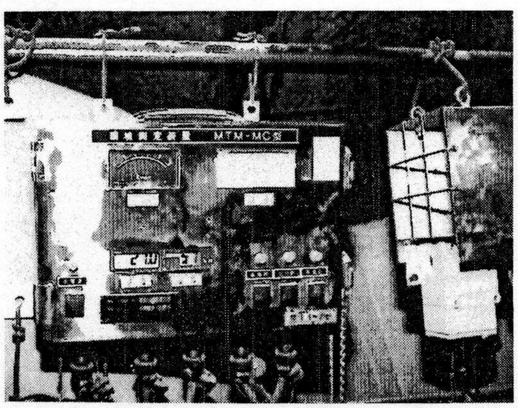


Photo 2. Sensors

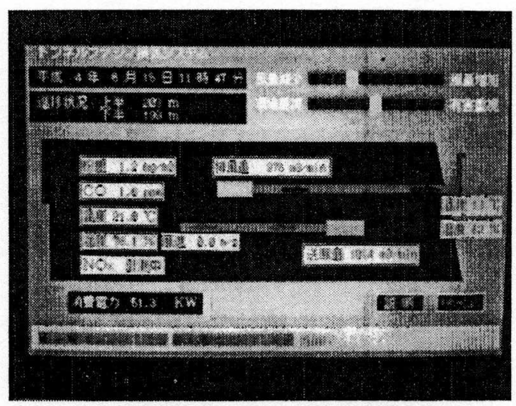


Photo 3. Monitored Screen