DIRECTIONAL CONTROL EMPLOYING FUZZY REASONING OF A MICROTUNNELLING SYSTEM

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ABSTRACT

NTT has developed a microtunnelling system with new directional control employing fuzzy reasoning which can construct a tunnel along the designed line well, in response to a shortage in experienced operators and the need to improve the working condition. Fuzzy reasoning, in which the know-how acquired from experienced operators are loaded, are certified using a dynamic model capable of predicting the behavior of driving machines. The field test in-site proved that the system is capable of providing a control facility equivalent to that of experienced operators.

Key words: fuzzy reasoning, directional control, microtunnelling

1. INTRODUCTION

Nippon Telegraph and Telephone Corporation(NTT) is constructing approximately 1,000km of underground cable conduits per year. Recently, due to environmental and economical reasons, the need for an efficient microtunnelling method has become increasingly important for outside plant engineering. Consequently, NTT has developed three kinds of small diameter pipe-jacking system (Called ACE-MOLE system) classified according to their diameter and penetration.[1,2,3]

The model 301, discussed in this paper, can make a pipe tunnel 300 mm in diameter using the nonmuck-discharge penetrating method. This system can construct a tunnel of up to 250 meters in length and 150 meters in curvature radius in comparatively soft ground (N-value less 10).

As quality of tunnelling work depends on the skill of operator, there is a great demand for experienced operators. Moreover, the amount of tunnelling work is now on the increase, and the shortage of experienced operators is creating a serious problem. What makes matters even worse is that it takes a considerable time to train. One way is to use a computer which can control the driving machine automatically to cope with these difficulties. However, automation of the directional control on microtunnelling has made little progress because the driving machines are controlled by human beings whose knowledge cannot be determined by ordinary control theory.[4,5]

Recently, Prof. L.A. Zadeh and Prof. E.H. Mamdani et al. have proposed the fuzzy set theory which obtain the numerical value of indefinite concepts like "large", "rather small" and "very high". Lately there are a great many applications of the fuzzy set theory for control of dynamic plants, automatic train operation and for directional control of shield tunnelling machines.[6,7,8,9,10]

Therefore, we have put the fuzzy set theory to practical use in directional control of microtunnelling and made an accurate system which is capable of providing a control facility equivalent to those of experienced operators. This paper deals with application of the fuzzy set theory for directional control and the results of a in-site field test.

2. SYSTEM OUTLINE

As shown in Figure 1, this system consists of a driving machine, pushing machine, power unit, control panel and control support system. This control support system is capable of recording construction data, can applying fuzzy reasoning and display the inteligent results for control on the CRT. This microtunnelling system has a particular position detecting, a directional correction method and a pipe-jacking method, makeing it possible to drive longer distance tunnels and follow a curved line.

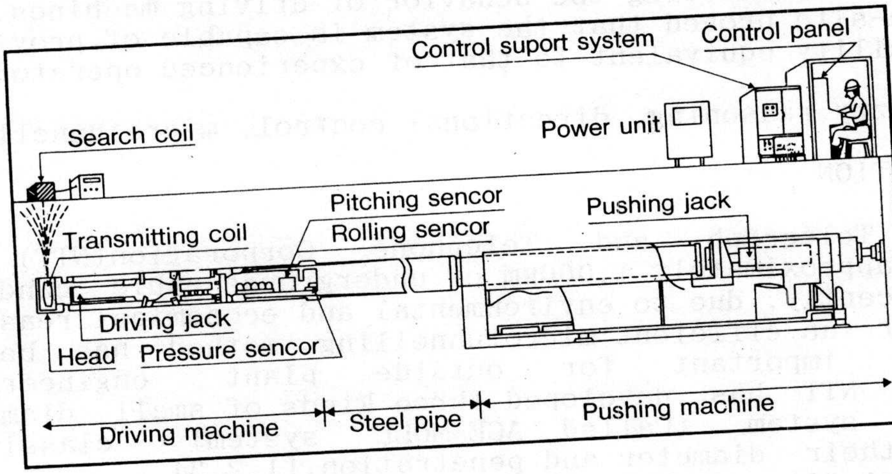

Fig. 1 System outline

The lateral position is determined by using the magnetic field emitted from a coil mounted inside the driving machine is detected by a search coil placed on the ground above. The vertical position is determined by detecting the difference between the value of the pressure sensor on the ground above and that of the pressure sensor mounted inside the driving machine. Pitching and rolling angles are also measured so as to estimate the direction of the driving machine.

To construct a pipe tunnel along a curved line, the directional correction method has been proven to be the most reliable. As for this system, the double-step-driving method in which both a driving jack and pushing jacks are operated alternately is used, and the head angle can be set at any angle. After the head is driven into the ground in the proper direction, driving machine and pipes are next jacked forward following the head. In this way, all necessary corrections can be made.

3. FUZZY RULE

In this system, directional correction can only be performed by changing the head angle, so operators have to determine the degree of the head angle based on not only the eroor but also their experience. We have defined the head angle and the pitching angle variation in Figure 2. Figure 3 shows the relation between the head angle and pitching angle variation using actual construction data. In this case, the head angle is the control input and the pitching angle variation is the amount of directional correction. It is general for the amount of directional correction to change as the hardness of the ground changes. Therefore, it is very difficult to clarify the relation between the head angle and the amount of directional correction. We intend to follow the operation of experienced operators in developing the fuzzy rule.

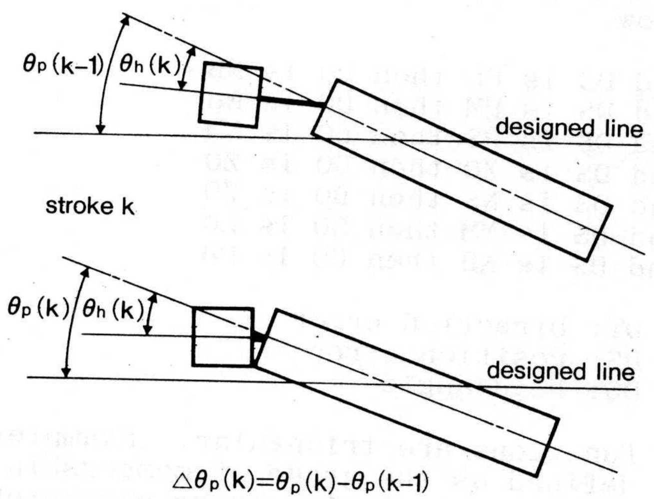

Fig. 2 Difinition of head angle and pitching angle variation

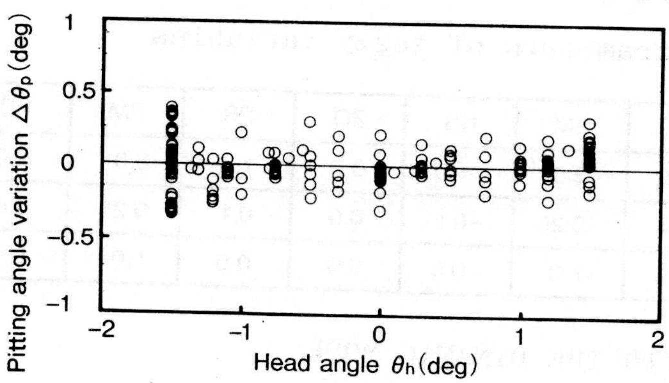

Fig. 3 Relation between head angle and direction correction amount

The main element and basic operation of experienced operators of directional correction are as follows.

Amount of position error
Amount of direction error
Direction error variation
Hardness of ground
Avoidance of a large correction if error is large

Concern with the direction rather than the position if they are small

We have discussed vertical operation because measured values are more reliable than that of lateral operation.

We have selected the direction and position errors as input variables, and also the head angle as the output variable in fuzzy rule. The label of the input and output variables are as follows.

PB: Positive big NB: Negative big
PM: Positive medium NM: Negative medium
PS: Positive small NS: Negative small
ZO: Zero

The number of fuzzy production rules are 49 with part of them being listed below.

If DT is PB and DS is PB then DO is NB
If DT is PM and DS is PM then DO is NB
If DT is PS and DS is PS then DO is NM
If DT is ZO and DS is ZO then DO is ZO
If DT is PS and DS is NS then DO is ZO
If DT is PS and DS is NM then DO is ZO
If DT is PS and DS is NB then DO is PB

where, DT: Direction error
DS: Position error
DO: Head angle

The membership functions are triangular. Examples of the parameter which are defined as the grade of membership function are equal to 1, are given in Table 1. These parameters are for rather soft clay ground.

Tab. 1 Parameters of fuzzy variables

	NB	NM	NS	ZO	PS	PM	PB
DS(cm)	-0.5	-3.0	-1.0	0.0	1.0	3.0	5.0
DT(degree)	-0.4	-0.25	-0.1	0.0	0.1	0.25	0.4
DO(degree)	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5

4. EXAMINATION WITH THE DYNAMIC MODEL

We evaluate the fuzzy reasoning using the dynamic model identified by Mr. Aoshima et al. which can be expressed by using the past pithing angle variation as the inertia effect and the head angles as control inputs. This dynamic model contains the past pitching angle variation using Eq. (1).[11]

$$\triangle\theta_p(k)=a1\triangle\theta_p(k-1)+\cdots\cdots+an\triangle\theta_p(k-n)$$
$$b0\theta_h(k)+\cdots\cdots+bn\theta_h(k-n)+e(k) \qquad (1)$$

where, $\triangle\theta_p(k)$: Pitching angle variation at stroke(k)
$\theta_h(k)$: Head angle
$e(k)$: Error
n : Model order
a1, ,an,b0,b1, ,bn : Constsnt parameter

Parameters in the dynamic model are identified using the least squares method, and a model order of 3 is selected. The identified parameters based on actual construction for two regions are shown in Table 2.

Tab. 2 Constant parameters

	a1	a2	a3	b0	b1	b2	b3
A region	0.168	0.113	0.093	-0.056	0.144	-0.007	-0.066
B region	0.633	0.089	-0.030	0.160	-0.090	0.012	-0.053

Here, we suppose that the designed line is horizontal, the direction error and position error are equal to the pitching angle and position of the driving machine.

The simulator is given by the Eqs. (2) and (3) and fuzzy reasoning using the result of $\triangle\theta_p(k)$ for Eq.(1).

$$\theta_p(k)=\theta_p(k-1)+\triangle\theta_p(k) \tag{2}$$

$$Y(k)=Y(k-1)+L\ \sin(\theta_p(k)) \tag{3}$$

where, $\theta_p(k)$: Picthing angle of the driving machine
Y(k) : Position of the driving machine
L : Length of one stroke

By substituting pitching angle $\theta_p(k-1)$ and position Y(k-1) into the fuzzy reasoning, control input $\theta_h(k)$ can be estimated. Next, directional correction $\triangle\theta_p(k)$ using Eq. (1) can be estimated. Then both pitching angle $\theta_p(k)$ and position Y(k) using Eqs. (2) and (3) are solved.

Here, fuzzy reasoning is carried out using the Min gravity method.

We examined how the error can be stabilized, with initial errors being given. Figures 4 and 5 show the simulation results using an initial error of -0.5 degrees and -5.0 centimeters. These simulation results show that fuzzy reasoning can stabilized the driving machine. The difference of how to stabilize between A and B region depends on the parameters of the dynamic model that is the difference of the soil condition.

Now, we apply another fuzzy rule in which control to access the designed line is a little strong. Figure 6 shows that the driving machine becomes a little unstable and changes in the head angle are in excess. Thus, we can determined the fuzzy rule for the soil condition.

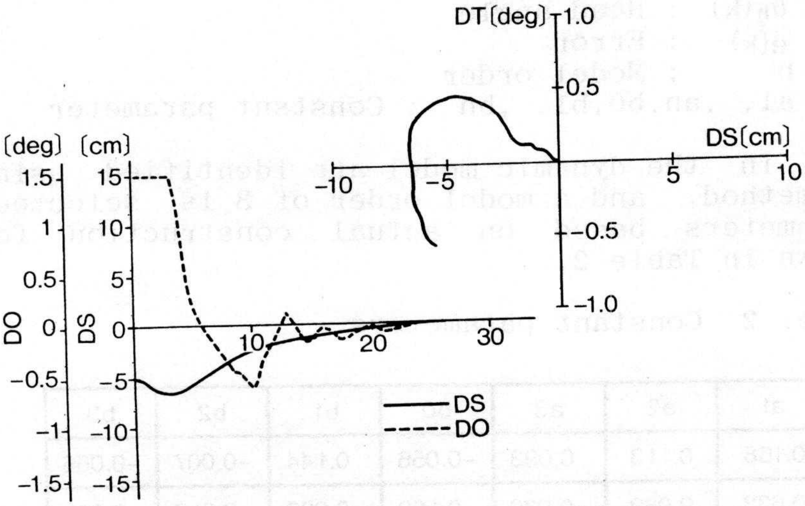

Fig. 4 Simulation sesult of A region

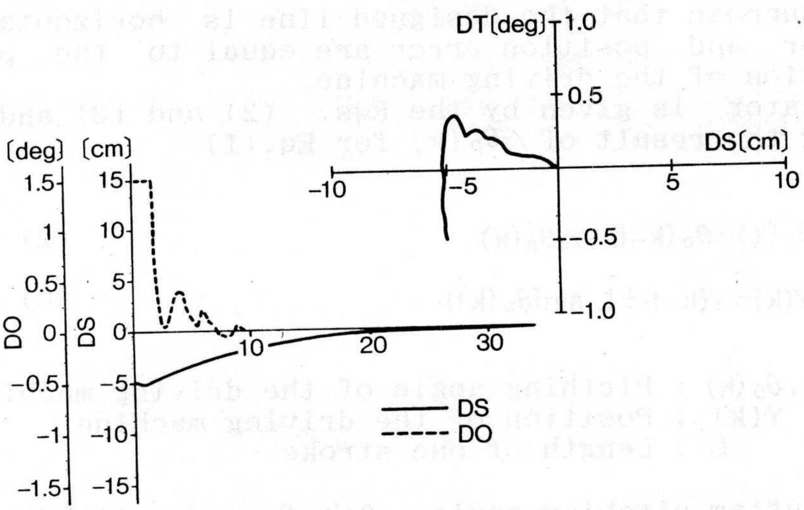

Fig. 5 Simulation result of B region

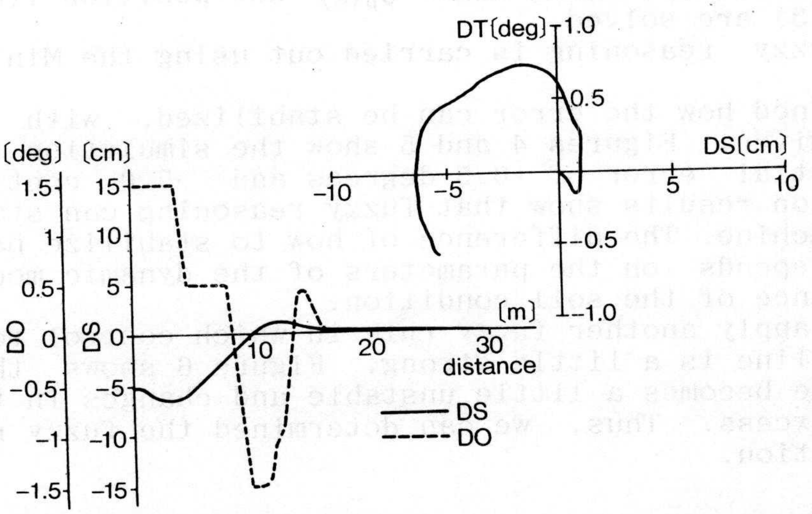

Fig. 6 Another simulation result of A region

5. EXPERIMENTAL RESULT

To evaluate the directional control facility employing fuzzy reasoning, we conduct a in-site field test. Here, fuzzy reasoning was carried out by FRUITAX made of Fuji Electric Co., Ltd.. Conditions of the field test are as follows.

Driving distance	:	30 m
Designed line	:	Holizontal
Depth	:	2 m
Soil condition	:	Loam, N-value=2, 3

The driving machine was set up with about -1.0 degrees of direction error. We drove the driving machine without control in 2.5 meters and with control employing fuzzy reasoning from there on. Figure 6 shows that fuzzy reasoning can stabilize the driving machine in field in-site. The responses to the corrections in the short distance are a little sensitive, since the fuzzy rule, if anything, is more suitable for soft soil. On the whole, it can be seen from this result that the system employing fuzzy reasoning is capable of providing a control facility equivalent to those of experienced operators.

When this system is applied for practical use, the fuzzy rule will need some changes so as to be suitable for the soil condition in-site.

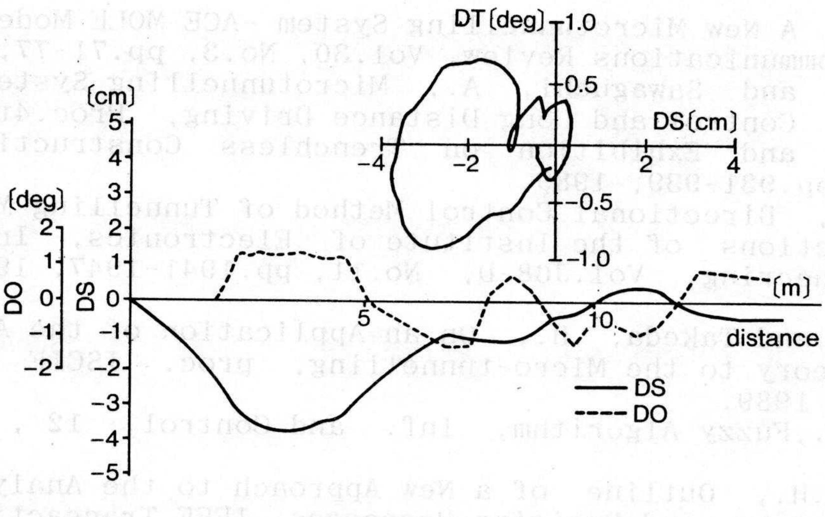

Fig. 7 Result of field test

6. CONCLUSION

First, as it is very difficult to clarify the relation between the head angle and the amount of directional correction, we studied directional control know-how from experienced operators, and made our fuzzy rule based on what we learned. Then, by using the dynamic model expressed by the past pitching variation, as the inertia effect and the head angles as control input, we could evaluated the fuzzy rule and obtain knowledge on the effect of changing rule. Finally, we conducted a field test employing the fuzzy reasoning fit for this type of ground with stabilized driving proving that the system is capable of providing a control facility equivalent to those of experienced operators.

This system, employing fuzzy reasoning, will contribute to higher productivity and quality of construction work and make remakable progress to the end goal of automatic microtunnelling processing.

Regarding practical use, as there are some distubances during driving, it will be necessary to change the fuzzy rule in this system. To this end, we will make effort to complete this system as intelligent expert system in which a knowledge base are accumulated.

7. ACKNOWLEDGEMENT

The authers would like to express their appreciation for the guidance of Mr. Hiroki Obata, Mr. Rikuo Takano, Mr. kazuo Toyokawa, Mr. Youji Oku and for the discussion of Mr. Yosihiko Nojiri, Mr. Takenori Morimitsu, Mr. Kazuyoshi Ooshima , and for the provision of the dynamic model by Mr. Shin-ichi Aoshima.

This is the product of combined efforts of Public Works Research Institute of The Ministry Of Construction and NTT.

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