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AN APPLICATION OF FUZZY CONTROL TO ANTI-SEASICKNESS
-- RESULTS FROM THE STABILITY ANALYSIS --

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ABSTRACT

Fuzzy control is applied to a ship to reduce its vertical motion in waves and then to avoid seasickness. Through the stability analysis, the characteristics of the fuzzy control system are discussed with full reference to the comparison between PID control. The fuzzy control system is found to be superior not only to its system stability but also to its smoothness without installing an undesirable filter. The scope of future applications of fuzzy control to more human-related purposes is described.

KEYWORDS: fuzzy control, system stability, ship motion, anti-seasickness, frequency analysis, vertical acceleration

INTRODUCTION

One of the control problems concerned with vehicles is motion sickness. In the case of a ship, especially a passenger ship, the problem is severer. Although it is said the seasickness is mainly due to the vertical acceleration or its differentiation, many other factors including physical and psychological conditions cause the seasickness and its mechanism is not completely revealed yet[1]. Conventional control system such as PID control is usually designed so as to minimize a certain cost functions such as a weighted summation of heaving deviation and control forces, so it is not always valid against the seasickness. For this reason we have applied the fuzzy control to an anti-seasickness system of a ship, and investigated the stability and the capability of the cabin stable system based on the linear system analysis.

ANTI-SEASICKNESS SYSTEM

The system was originally designed using PID control but the unique idea of the system is to separate a cabin structure completely from the main hull connected by hydraulic-driven cylinders[2]. The simplified configuration of the system is shown in Fig. 1 and the block diagram of the control system is shown in Fig. 2.

Defining Xs as the axis of the center of gravity of a ship, Xp as that of the connecting point of the cylinder and the spring-damper system, and Xc as that of the cabin, the differential equation of the heaving motion of the cabin is derived as follows:

$$d^2Xc/dt^2 = -2\zeta\omega_n(dXc/dt-dXp/dt)-\omega_n^2(Xc-Xp)$$

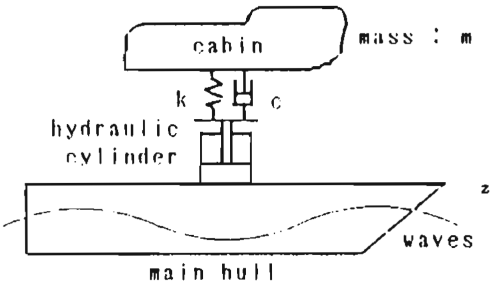


Fig. 1 Simplified configuration of a cabin stable system

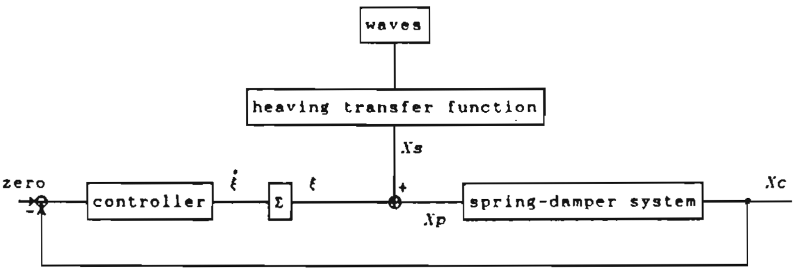


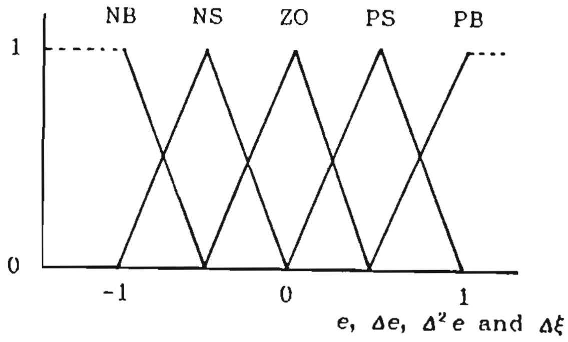
Fig. 2 Block diagram of the cabin stable system

where ω_n is natural angular frequency; $\omega_n = \sqrt{k/m}$, and ζ is damping coefficient; $\zeta\omega_n = c/2m$.

As for the inputs of the fuzzy controller, we select vertical displacement, velocity and acceleration. A general form of the fuzzy rules in this controller is expressed as follows:

If e is A, Δe is B and $\Delta^2 e$ is C, then
$\Delta\xi$ is set as D

where each of e, Δe, $\Delta^2 e$ is heaving deviation, velocity and acceleration, and $\Delta\xi$ is piston speed. A, B, C and D are either of linguistic variables "NB", "NS", "ZO", "PS" or "PB" respectively.



In this figure, -1 ~ 1 of the horizontal axis is determined to normalize as follows:

e : -0.52 ~ 0.52 (m)

Δe : -1.5 ~ 1.5 (m/s)

$\Delta^2 e$: -6.0 ~ 6.0 (m/s^2)

$\Delta\xi$: -3.0 ~ 3.0 (m/s)

Fig.3 Normalized membership functions

: where $\Delta^2 e$ is NB.

e \ Δe	NB	NS	ZO	PS	PB
NB			PB		
NS			PB		
ZO	PB	PB	PB	PS	ZO
PS			PS		
PB			ZO		

: where $\Delta^2 e$ is NS.

e \ Δe	NB	NS	ZO	PS	PB
NB			PB		
NS			PB		
ZO	PB	PB	PS	ZO	NS
PS			ZO		
PB			NS		

: where $\Delta^2 e$ is ZO.

e \ Δe	NB	NS	ZO	PS	PB
NB	PB	PB	PB	PS	ZO
NS	PB	PS	PS	ZO	NS
ZO	PB	PS	ZO	NS	NB
PS	PS	ZO	NS	NS	NB
PB	ZO	NS	NB	NB	NB

: where $\Delta^2 e$ is PS.

e \ Δe	NB	NS	ZO	PS	PB
NB			PS		
NS			ZO		
ZO	PS	ZO	NS	NB	NB
PS			NB		
PB			NB		

: where $\Delta^2 e$ is PB.

e \ Δe	NB	NS	ZO	PS	PB
NB			ZO		
NS			NS		
ZO	ZO	NS	NB	NB	NB
PS			NB		
PB			NB		

Table 1 Matrices of fuzzy control rules

1976

Normalized form of the membership functions is shown in Fig.3, and the rules are summarized as in Table 1. As you can see from the table, we only set the rules where at least one "ZO" is included in either of the inputs. The fuzzy controller is then tuned so as to behave similar to a PID controller by trial and error.

STABILITY ANALYSIS

Generally, it is impossible to discuss the stability of a fuzzy controller explicitly, because the approximate reasoning itself is nonlinear. By linear approximation, however, we can estimate the relationship between the input and the output of fuzzy controller, utilizing the classical control theories such as Bode's or Nyquist's diagrams. Fig. 4 indicates Nyquist's diagram of the fuzzy control system compared with the equivalent PID controller. Both gain margin and phase margin work to achieve more effective from the viewpoint of stability according to the increase of the input amplitude. It is also shown that the PID controller with low-pass filter makes the system less stable.

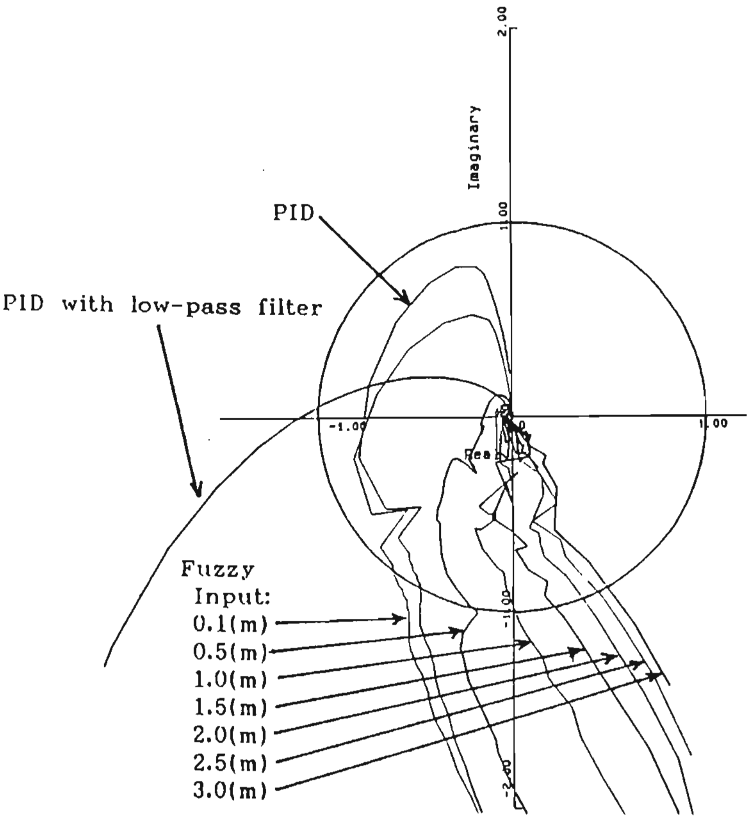


Fig. 4 Nyquist's diagram (Overall transfer function)

SIMULATION RESULTS

Numerical simulations were carried out for irregular heading waves. The ship used for the simulation is a container ship of 175m length, 25.4m width, 8.5m draft and of 21,753ton displacement. Heaving transfer function of the ship was calculated using a potential theory, and irregular wave was created to simulate the wave spectrum generated by 15m/s wind blow[3]. Fuzzy calculation was based on Mizumoto's method[4]. A result of the simulation is shown in Fig. 5. PID controller can reduce the heaving amplitude of the cabin nearly half compared with no-control result, but it involves high frequency movement corresponding the high frequency noise of waves, sensors etc. Low-pass filter is essential to exclude the high frequency movement for mechanical protection or for smooth response. However, it turns the system stability worse as shown in Fig. 4 and actually the heaving amplitude increases at some portion compared with PID controller. On the other hand, the fuzzy controller achieves the similar reduction of heaving amplitude to PID controller as well as the similar smooth response to PID with low-pass filter.

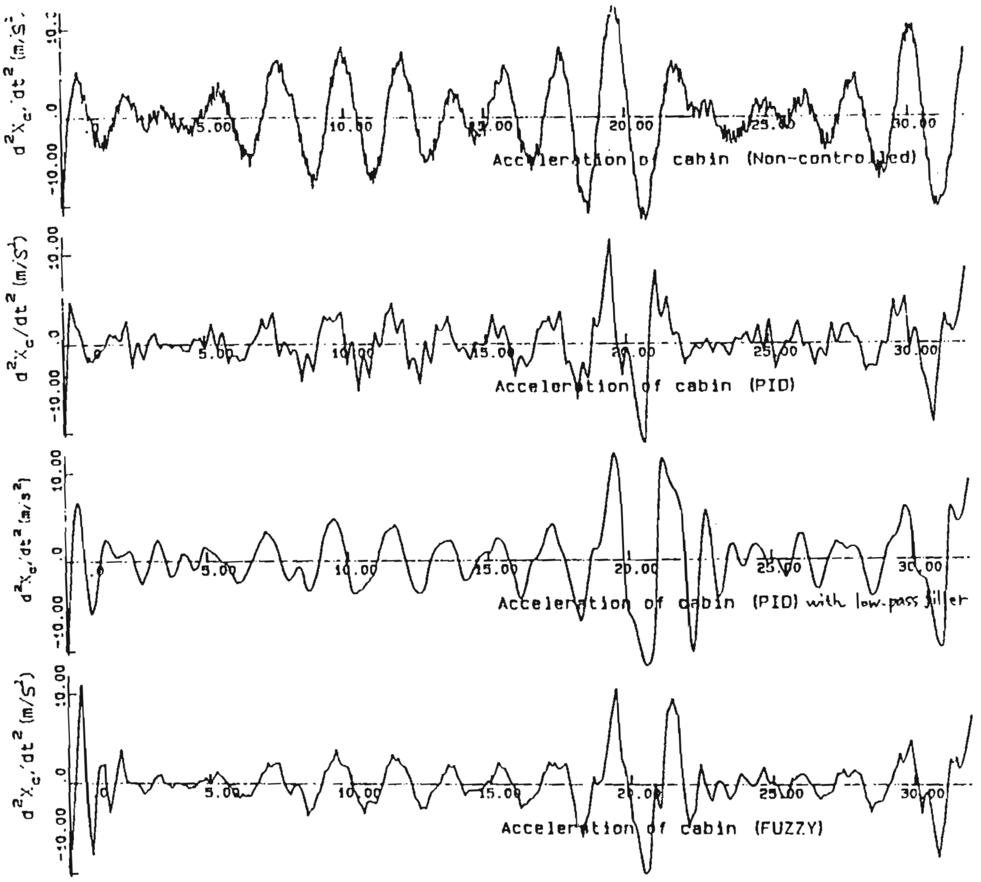


Fig. 5 Simulation result of the cabin stable system

CONCLUDING REMARKS

As far as ships are concerned, we cannot completely control motions against waves. The design principle of conventional control systems is based on the minimization of deviation and control effort. They ignore human perception to which seasickness is, by the way, deeply related. Fuzzy control seems to be suitable to such an application. As a first stage of research, we have investigated the system stability and the smoothness of fuzzy control in an anti-seasickness system. The results are satisfactory and promising. We have shown another possibility of merit of utilizing fuzzy control.

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