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INTELLIGENT CONTROL OF A MULTI-DEGREE-OF-FREEDOM REACTION COMPENSATING PLATFORM SYSTEM USING FUZZY LOGIC

Benjamin B. Choi and Charles Lawrence
NASA Lewis Research Center
Cleveland, Ohio

and

Yueh-Jaw Lin
University of Akron
Akron, Ohio

ABSTRACT

This paper presents the development of a general-purpose fuzzy logic (FL) control methodology for isolating external vibratory disturbances of space-based devices. According to the desired performance specifications, a full investigation regarding the development of an FL controller was done using different scenarios, such as variances of passive reaction-compensating components and external disturbance load. It was shown that the proposed FL controller is robust in that the FL-controlled system closely follows the prespecified ideal reference model. The comparative study also reveals that the FL-controlled system achieves significant improvement in reducing vibrations over passive systems.

INTRODUCTION

Passive systems may perform effectively in reducing vibration caused by the vibration object when the operating frequency of the object is high. However, their performance is serious degraded in the low frequency range. Hence, active vibration isolation systems may appear to be the only means to overcome vibration isolation problems in the low frequency range. Although the benefits of using active vibration compensating systems are obvious, it requires a high-performance control system that is capable of handling all undesirable dynamic disturbances in an extremely short period of time. In particular, a robust control system that provides a wide range of dynamic disturbance compensating capability, is the key to a vibration-free dynamic environment. Toward this end, some recent advancements in active vibration control schemes [1-5] have been evident. They have been able to reduce the level of vibration to a certain extent, their limitations and performances are still far from being satisfactory. Therefore, there is a need of developing a new control system with good intelligence and robustness such that it can cope with rapid varying vibratory disturbances in a real-time manner.

To accomplish this, a fuzzy logic algorithm that possesses the nature of mimicking human thinking, is proposed for the desired intelligent control system. Due to the fuzzy nature of the proposed control system, potential dynamic disturbances are identified and classified into distinct groups. For each group of identified disturbances a unique control action will be taken to compensate for the undesirable disturbances. The control actions may be adjusted from time to time based on a set of adaptive fuzzy rules designed specifically for a particular application, such as the control of the platform system under study.

DYNAMIC FORMULATIONS

The configuration of the two-plate platform system is shown in Figure 1. In the first stage of the study, comprehensive dynamic formulations of the six-degree-of-freedom platform system were formulated by applying Lagrange's and Newton-Euler methods. Since Newton-Euler formulation is more structured and hence easier to be manipulated, it was further linearized and utilized for system dynamics and control investigation. Detailed derivations of dynamic formulations are omitted due to space limitation.

PASSIVE DYNAMIC RESPONSES

Passive responses in terms of the bottom plate acceleration and displacement occurred at four different locations of interest on the top and bottom plates, namely, the center and the three actuator locations, are studied. The translational responses of the three actuator positions are shown in Figure 2. In this study, it is simulated to be an impulsive force of 445 N (100 lb) for 0.5 second.

FUZZY LOGIC CONTROLLER DESIGN

Referring to Figure 3, the measured accelerations of the bottom plate at the three actuator positions are used as the control feedback signals. After they are compared with the desired zero acceleration the resultant error signals are then used to fire the fuzzy engine residing in the fuzzy logic controller. The desired performance of the fuzzy-logic controller will be achieved when the detected accelerations reach the prespecified tolerances. The three actuators are controlled by three different fuzzy-logic controllers whose fuzzy logic rule bases are set up independently, according to the passive dynamic responses at their respective locations.

The basic architecture of the designed fuzzy-logic controller is depicted in Figure 4. Basically, it consists of four principal components: scaling, fuzzification, decision making process, and defuzzification. The scaling factors map the controller inputs $e(t)$, $\Delta e(t)$ and controller output $\Delta u(t)$ to and from the normalized intervals in which the fuzzification and defuzzification processes take place. The controller inputs $e(t)$ and $\Delta e(t)$ are chosen to be the bottom plate acceleration error and its variation, respectively. The controller output $\Delta u(t)$, however, represents the resultant actuation force.

The universe of discourses for the two inputs are determined by using the passive dynamic acceleration responses of the bottom plate shown in Figure 2. More specifically, the maximum/minimum amplitudes and slopes are utilized. However, the universe of discourses of the output $\Delta u(t)$ are determined based on the actuator's capability. In addition, they are further discretized into seven quantization levels. Then, a fuzzy set is defined by assigning grade membership values to each discretized segment.

Seven linguistic variables are used and correspond to the peaks of the seven triangular membership functions. The overlaps of two adjacent membership functions are uniformly determined to be 45°. This is then followed by the fuzzy decision-making process, which is performed by an interface engine that matches the conditions of all the rules and determines the partial degree of matching of each rule. Finally, it aggregates the weighted output of the rules, generating a possibility distribution of the values on the output universe of discourse.

The resultant fuzzy output set are listed in Table 1, as a look-up table, which defines the output of the controller for all possible combinations of the input signals.

CONTROLLER PERFORMANCE EVALUATION

A comparative study of the dynamic responses of the passive and active fuzzy logic controlled platform system is carried out. Figure 5 shows the time domain acceleration responses of the passive and the controlled systems. Responses at actuator positions 2 and 3 are similar. It is clear that the fuzzy logic controller reduces the accelerations at each actuator position of the bottom plate by about 90% over the passive system. Figure 6 shows the dynamic behavior of the center of the bottom plate.

The simulation results reveal that the acceleration of the center of the bottom plate, which is a critical measure of the performance of the entire platform system, only sightly off against the desired zero acceleration line through the entire simulation history due to the compensation of the fuzzy logic controller. This verifies that the developed fuzzy logic controller is effective for the reduction of undesirable vibratory accelerations.

Moreover, comparisons of the displacement responses of the platform bottom plate between the passive and active controlled systems are made. They also show that with the fuzzy logic active control, all four displacement responses stay around the zero displacement line through the entire simulation period, only with some ignorable offsets.

CONCLUSION

In the first stage of the study, comprehensive dynamic formulations of the six-degree-of-freedom platform system were formulated by applying Lagrange's and Newton-Euler methods. Since Newton-Euler formulation is more structured and hence easier to be manipulated, it was further linearized and utilized for system dynamics and control investigation. Based on the compensation requirement with a desired (reference) zero acceleration of the platform bottom plate, a fuzzy logic controller was designed. Dynamic and control motion simulations were performed in terms of comparative study of the passive uncontrolled and the active controlled platform system. The results showed that the designed fuzzy logic controller possesses the following features: a) it is robust and hence less sensitive to the disturbance input variations; b) it is easy to design and hence eliminating the tedious gain selection process required in conventional controller design; c) its speed of response is rapid; d) it is adaptive in that the fuzzy rule-base is adjustable; and e) it is readily implementable by microelectronic devices since it uses logical operations.

In light of the comparative study shown in the simulation results, it was demonstrated that the designed fuzzy logic controller could almost completely eliminate undesirable vibratory accelerations of the bottom plate induced by the specific impulsive disturbance. The effectiveness of the fuzzy logic controller was further confirmed by viewing the significant reductions of bottom plate's displacements shown in the comparative study.

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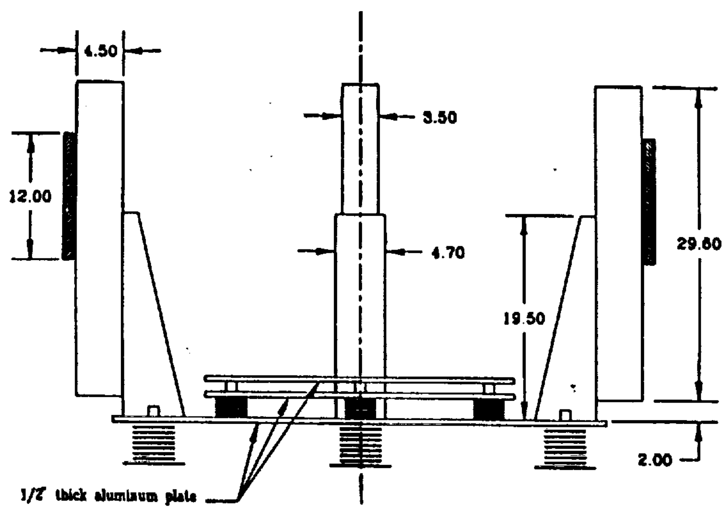

Figure 1. Configuration of the platform system.

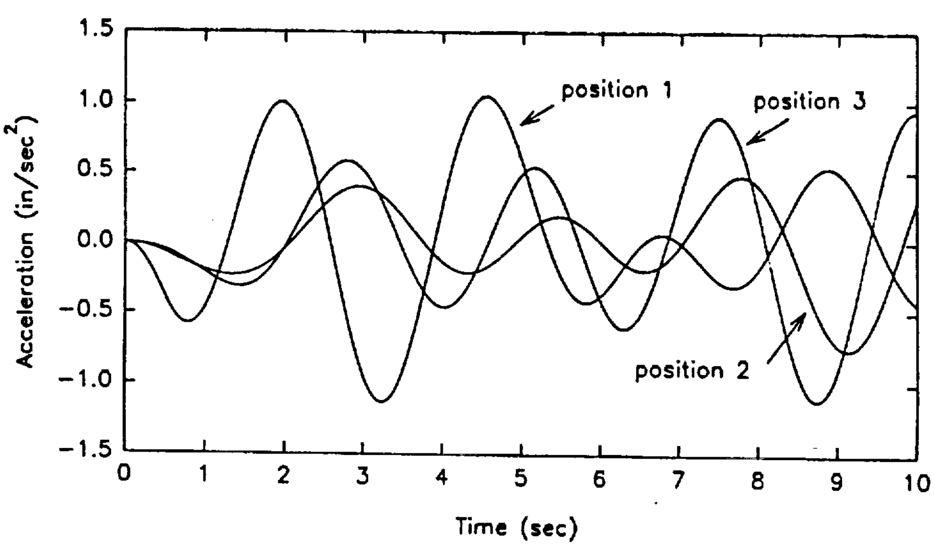

Figure 2. Passive acceleration response at actuator locations.

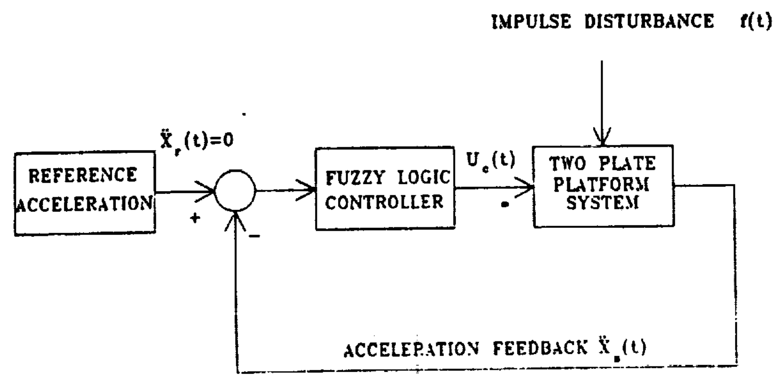

Figure 3. Block diagram of the entire control system.

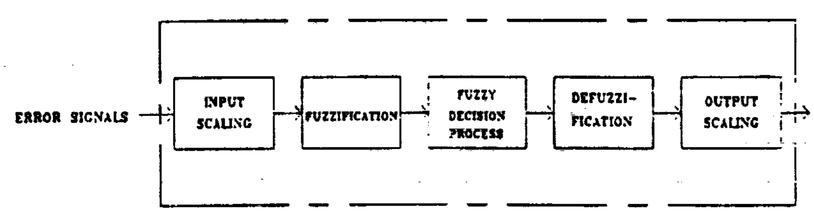

Figure 4. Basic architecture of a fuzzy logic controller.

Table 1. Designed fuzzy logic rule base.

Δe \ e	NL	NM	NS	ZE	PS	PM	PL
NL	-3	-3	-2	-1	0	1	2
NM	-3	-2	-2	-1	1	1	2
NS	-3	-2	-2	0	1	2	3
ZE	-3	-2	-1	0	1	2	3
PS	-3	-2	-1	0	2	2	3
PM	-2	-1	-1	1	2	2	3
PL	-2	-1	0	1	2	3	3

-3	NL
-2	NM
-1	NS
0	ZE
1	PS
2	PM
3	PL

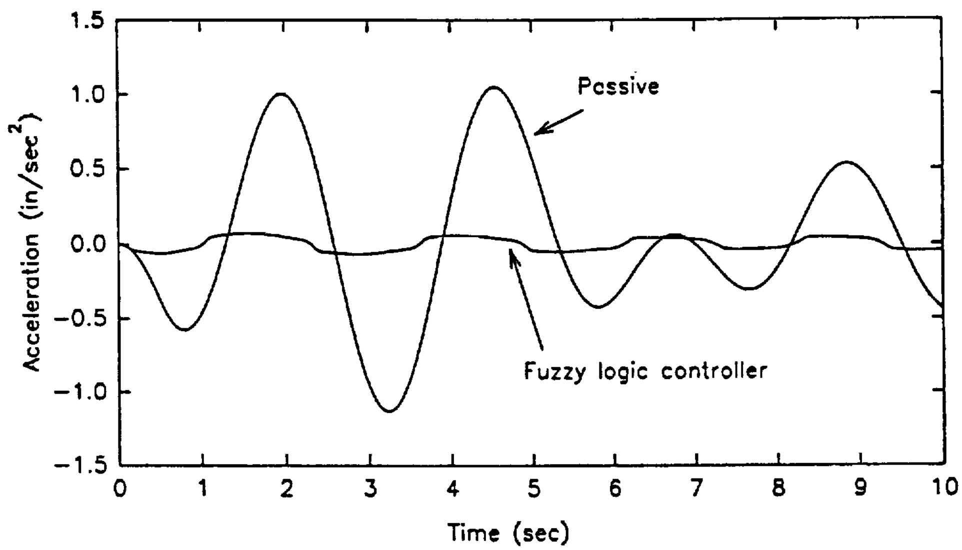

Figure 5. Comparison of acceleration response at actuator 1.

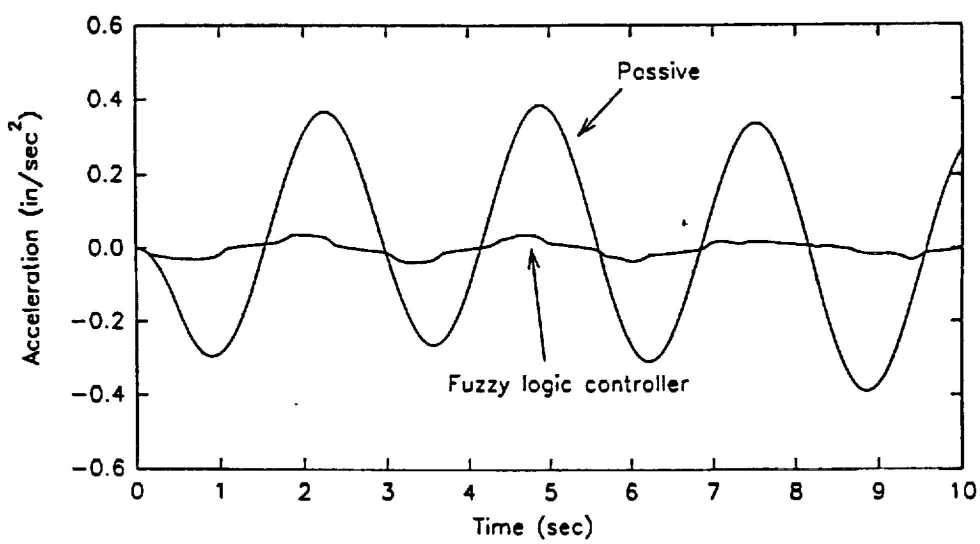

Figure 6. Comparison of acceleration response at the center.