Fuzzy Logic Washout Algorithm Based on Serial Manipulator

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Abstract. The previous motion simulator is almost all built on the basis of parallel mechanism, and the most used and most mature is based on the six degree of freedom steward platform, and the simulator of the series mechanism has not been widely studied. Because the body organs can not accurately distinguish the degree of motion, the theory of fuzzy control is introduced to improve the classical wash out algorithm, and the motion error of the sensory organ of the vestibule of the human vestibule and the space of the motion platform are combined, and the fidelity of the motion simulation can be raised as much as possible under the limit of the non super motion platform.

Introduction

The motion simulator, which appeared in the 70s of last century, is widely used in flight simulation, vehicle road simulation, aviation and navigation simulation, robot, parallel machine tool, space docking technology and entertainment facilities by simulating the movement of aircraft and ships in the motion simulator[1].

The motion platform of series mode has large motion range, fast response speed, simple control and low cost. Moreover, the development of hardware makes the load and control precision greatly improved. It makes it more feasible to design an effective free degree series motion platform in motion simulation, and with domestic games and amusement's opening and vigorous development, especially the development of virtual reality technology, has stimulated the design and development of many recreational and sports simulation[2]. Therefore, it is of great practical significance and value to study the motion simulator of the series mechanism.

Logic Control and Wash Out Algorithm

Model of Manipulator

The manipulator is modeled by SolidWorks, whose model is shown in Figure 1. The mechanical arm, referring to the structure of the human arm, uses an open - chain joint structure, which is divided into the large arm, the small arm and the wrist, as well as the revolving lumbar and wrist joints. The mechanical arm has 5 degrees of freedom without a transversal movement of freedom.
Human Vestibule Perception System

The vestibular organ model was introduced to evaluate it[3]. Specific force and linear angular velocities through the vestibular sensory system, then the real somatosensory motion signals are obtained, as a reference signal; the specific force and linear angular velocities are obtained by the wash out algorithm and the vestibule sensory system, and the reference signal and the wash out signal form the error signal e. As shown in Figure 2.

![Figure 2. Contrast between the estimate and original signal.](image)

Fuzzy Logic Wash Out Algorithm

As shown in Figure 3, the input joint angle limit l and its change rate dl signal enter the fuzzification module after normalization. The signals obtained by the inference engine and the rule base are solved by the solution gelatinized output signal e, and then feedback to the fuzzy logic was out algorithm.

![Figure 3. Block diagram of fuzzy logic control.](image)

Shown in Figure 4, the signal e is fed back to the high pass channel, and through the feedback, the feedback can be fed into the high pass channel. In order to reduce the error of acceleration sense and angular velocity, the dynamic fidelity of the simulator is improved. The linear acceleration and linear angular velocity directly pass through the vestibule sensory system to get real motion sensory signals (reference signals); on the other hand, because the motion space of the simulator is limited, the real motion state of the aircraft can not be completely recounted, and the reappearance of the aircraft is needed through the wash out algorithm.

![Figure 4. Fuzzy logic wash out algorithm.](image)
**Input.** Input signal 1 is the position limit of the motion simulation platform (l), for the degree that the rotation angle of each joint of the five axis manipulator is close to the limit value, the rotation angle of each joint is close to the maximum value of the limit value as the input of the fuzzy controller. However, the range of motion of each joint is inconsistent. How to assess the extent of the approaching limit is worth quantifying. We can get the quantitative description function of the degree of near motion limit of each joint angle.

\[
l_i = \sqrt{\frac{\theta_i - \theta_{li}}{\theta_{hi} - \theta_{li}} \left( i = 1,2,3,4,5 \right)}
\]

\[
l = \max(l_i)(i = 1,2,3,4,5)
\]

Where: \( \theta_{li} \) is the limit of each joint angle, and \( \theta_{hi} \) is the upper limit.

We use the maximum l of the joint limit as the input signal of the two-dimensional fuzzy logic controller. The domain of l is [0,1], divided into 5 fuzzy sets, A, B, C, D, E.

![Figure 5. The degree membership of the joint angle limit.](image1)

The input signal 2 is dl for the change rate of L. The degree membership of the dls is shown in figure 6.

![Figure 6. The degree membership of the dl.](image2)
Output. The linear acceleration and linear angular velocity are washed out by the fuzzy logic elution algorithm and the vestibule sensory system. The reference signal and the eluate signal form the error signal e as the output signal of the fuzzy logic controller. Its membership function is shown in Figure 7.

Figure 7. The degree membership of the e.

Fuzzy rules. The description of fuzzy rules in fuzzy logic controller: when the limit value L of the joint angle is larger, the smaller compensation value should be considered. If the change rate dl is negative, a slightly larger compensation value should be selected and a smaller compensation value is selected if the change rate dl is positive. When the joint angle limit value L is hourly, the larger compensation value should be considered, if the change rate dl is negative, select a little bit. Large compensation value, if the change rate dl is positive, choose a smaller compensation value. The fuzzy rules are shown as shown in Table 1.

Table 1. Fuzzy logic rules table.

| e'   | NB | NS | NO | PS | PB |
|------|----|----|----|----|----|
| A    | E  | E  | E  | D  | D  |
| B    | E  | E  | D  | C  | C  |
| C    | D  | D  | C  | B  | B  |
| D    | C  | C  | B  | A  | A  |
| E    | B  | B  | A  | A  | A  |

Fuzzy inferences. R: if x is A, and y is B, then z is C, \( R = (A \land B) \rightarrow C \); where: x, y represents the language variables of the state of the system, z represents the language variables of system control, A, B, C are fuzzy values of x, y, z, the domains of x, y, z are \( X, Y, Z \), as shown in Formula 3, Formula 4 and Formula 5[4].

\[
\mu_R = \mu_{A \land B \rightarrow C}(x, y, z) = [\mu_A(x) \land \mu_B(y)] \rightarrow \mu_C(z) \tag{3}
\]

\[
R = \bigcup_{i=1}^{m} R_i \tag{4}
\]

\[
C = [\mu_A(x) \land \mu_B(x)] \circ R \tag{5}
\]

Simulation of Wash Out Algorithm

The algorithm is designed to quickly return to the equilibrium position after simulating a mutation in a limited space, so that there is enough space for the next movement, and in the process of return it must be lower than the perceptual threshold of the human body[5].
By modeling and simulation in MATLAB/Simulink, the signal of step acceleration of 2m/s² is selected, the acceleration changes to 3m/s² at 2s, the acceleration becomes 0m/s² at 3s, the acceleration changes to 3m/s² at 7s, and the acceleration becomes 0m/s² at 9s. The high pass cut-off frequency $\omega_{hps}$ was $2.5\text{rad/s}$, and the high pass cut-off frequency $\omega_{lfx}$ was $8\text{rad/s}$.

The simulation results are shown in Figure 6.

![Figure 8. The simulation results.](image)

From Figure 8, it is found that the fuzzy logic washout algorithm has a better washout effect than the classical washout algorithm. The sensory error has been reduced, and the fidelity of simulation has been improved.

**Summary**

This paper researches on the motion simulation technology based on five axis manipulator. In order to evaluate the washout effect reasonably, the human vestibular sensing system is introduced to get the sensory error. In addition, fuzzy logic is used to improve the washout algorithm and simulate it. It is found that the fuzzy logic washout algorithm achieves better simulation fidelity than the classical washout algorithm.

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