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The Motion-sensing Simulation of Dynamic Seat

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Abstract*: At present most of the dynamic seat are made by three degrees of freedom platform as the foundation. This paper based on the six degrees of freedom motion platform Stewart parallel mechanism, which analyze the movement of human body physiology, sensory, deep understanding of human movement and dynamic response of the human body movement sensory that model is established.In order to improve the fidelity of the dynamic seat, high order washout filter algorithm was designed to match the human body physiology characteristic to make the audience get a better motion perception.*

Keyword: *Dynamic seat; six degrees of freedom motion platform; Movement senses; Higher-order wash the filter algorithm*;

I. Introduction

The rapid development of dynamic cinema and dynamic platform, virtual reality technology and its control mode of study are inseparable, and dynamic seat are the most core components in dynamic cinema, its effect directly affects the audience watch the effect. Since the six degree of freedom parallel mechanism was born, it famous for its simple structure, convenient maintenance and excellent athletic performance which becomes one of the highlights in agro-scientific research in the universities and research institutions. Also for its high rigidity, recommend suite, low inertia, high precisionetc, the characteristics of the six degree of freedom parallel mechanism in the commercial, military, education and other industries has been widely attention and application.Its mechanism is shown in figure 1.

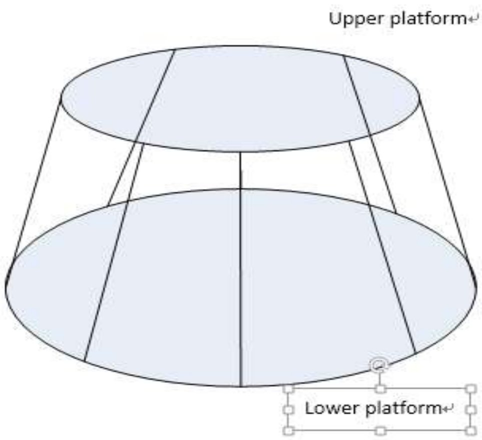

Figure 1

Filter is a device or circuit of signal processing effects. Main function is improving the useful signal by as much as possible without attenuation and attenuating the useless signal attenuation as large as possible. Filter generally has two ports, one input signal and an output signal. Using this feature can be through a square wave group or compound filter noise, and get a certain frequency sine wave. Filter types mainly include Butterworth response (the flat response), Bessel's response, and Chebyshev response of three types.

II. Six Dofmotion Platform Washoutfilteralgorithm

Washout filter algorithm is designed to make the motion perception of six DOF motion platform in the limited working space to provide consumers with the real environment can feel. In the dynamic seat signal dynamic model output, some high frequency and low frequency signals cannot feel, so signal washout filter algorithm by these people cannot feel the removal to reduce the amount of motion platform. Another function of the filter is to make an action in the dynamic seat, so that the platform is not aware of the acceleration of the recovery to the initial position, so that it can continue to the next action. Six degree of freedom motion platform after acceleration filtercan ensure that the dynamic seat movement will not exceed the mechanical limit of the motion platform, especially the drive of the maximum available displacement and maximum allowable speed. By tilting and coordinating the motion platform, the gravity component can be used to provide consumers with continuous acceleration sensing. Although the seat can provide sustained acceleration perception, but the rotation caused by the tilt of the cockpit is lower than the vestibular threshold. Therefore, the movement of the platform can be effectively avoided and the motion perception can be avoided when the inclined seat is simultaneously passed through the platform. The washout filter algorithm mainly includes classic washout filter algorithm, adaptive washout filter algorithm and the optimal washout filter algorithm three[1]. The classical washout algorithm[2-4] is the earliest, which is also the most widely used proprioceptive simulation algorithm. The classical washout algorithm using high and low pass filter to solve the limitation of range of motion simulation platform, design and computing process is relatively simple and easy to perform faster, less parameters according to the feedback adjustment and optimization. But in the process of simulation platform motion parameters in the classical washout algorithm is fixed, this characteristic causes the platform must be in order to limit action under the condition of debugging. In this case, the filter is not in the limit of the filter when the vehicle is in the state of motion, the action of the platform will appear relatively conservative. Therefore, in order to optimize the response of different carriers must be readjusted to the washout algorithm. In the normal operation of the vehicle, the limit state is relatively small, and the filter parameters in the limit state cannot reach the best effect when the vehicle is in the non -limit state. The optimal washout filter[5]has been a hot topic in the field of somatosensory simulation.Its performance adjustment is not directly change the filter parameters but the transfer function by changing the weights of clear physical meaning to make people feel error motion simulator platform on the minimum movement. But these weight parameters have no clear physical meaning, which leads to very complex debugging. And the degree of accuracy of vestibular organs directly affects the optimal control model of the fidelity of the washout algorithm, verification method and the degree of accuracy of the vestibular organ model nor a standard. The adaptive washout algorithm[6]uses the online identification method which summed up the object movement to improve the mathematical model of the system according to the change of state parameters in real time algorithm of moving platform, combining with the optimal control method to design the filter to make up for the shortcomings of classical algorithms. But the adaptive washout algorithm of complex function is not easy to adjust, more variable parameters, calculation and comparison of high real-time requirements. The practical application proves that the simulation of the algorithm has not been greatly improved and improved because of the many complicated factors and the theory.

2.1 FilterOrder

The order of the filter is the number of poles in the designed filter transfer function, which determines the attenuation rate of the filter response in the transition region. The order of the filter is mainly influenced by the acceleration scale factor and the tilt coordination in the simulator motion system. Improving the order of the low pass filter on the tilt coordination channel can improve the performance of low frequency acceleration. Tilt coordinate filter order of horizontal channel influence, including translation along the direction of X, Y axis and two axis around the rotating direction. The influence of the order of the filter on the acceleration ratio is mainly reflected in two aspects. Firstly, it will affect the size of the inclined channel signal along the X axis X and Y axis, and if the acceleration ratio coefficient increases, the angle of the tilt angle will be increased; Secondly if the acceleration ratio is less than 1, high acceleration washout filter algorithm will not get the input acceleration signal gain complete. So it is very important to choose the appropriate filter order. According to the frequency characteristics of the filter can be divided into low pass filter, high pass filter, band-pass filter, band-pass filter and all-pass filter [7].

2.2 Ratio Limit

To avoid trigger movement during the drive to limit position and need to use the soft limit to smoothing six drive motion, as shown in figure 2. When the drive length exceeds M_t, the smoothing process is applied.

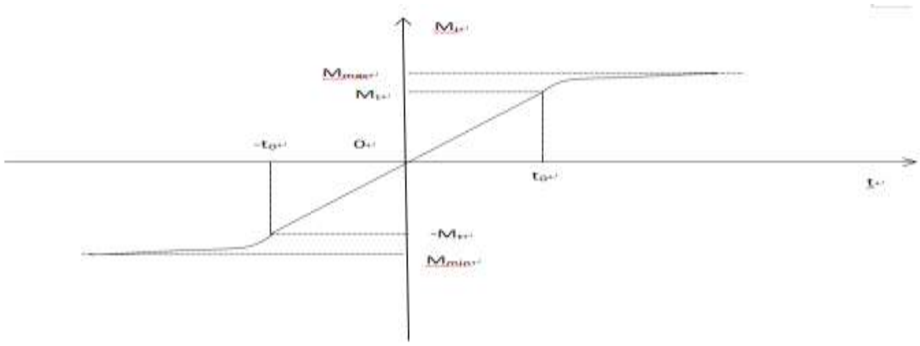

Figure 2 Actuator soft limits

2.3The Design of the High-pass Filter

The high pass filter can respond to instantaneous changes, which can be used to simulate the instantaneous acceleration, and realize the initial sensing of the linear acceleration. However, due to the limit of the drive travel, the acceleration of the movement will quickly weaken. The role of the high pass filter is to generate the initial motion perception, and to eliminate this perception before reaching the maximum stroke of the drive. The high pass filter is designed to be a three order system, where the input acceleration limit is set to 1g, with the increase of speed, the acceleration input is gradually reduced by feedback. Similarly, with the movement of the upper platform, the speed and acceleration of the platform will be gradually reduced to 0 by the feedback term. Finally, the position of the upper platform is zero based on the integral term.

2.3.1Qualcomm Linear Acceleration Channel

The transfer function formula of the three order high pass acceleration channel is as follows,

$$\frac{\ddot{s}_m}{\ddot{s}_i} = \frac{s^2}{s^2 + 2\delta\omega_0 s + \omega_0{}^2} \times \frac{s}{s + \omega_1} \text{ (2-1)}$$

Among them, $\ddot{s}_i$ for input position; s_m for the output position; δ for damping; $2\delta\omega_0$ for the implementation of the viscous damping; $\dot{s}_m$ is the position of the moving platform after transformation.

The formula of feedback coefficient k_1 and k_2 are respectively

$$k_1 = \omega_1 + 2\delta\omega_0 \text{ (2-2)}$$

$$k_2 = 2\delta\omega_0\omega_1 + \omega_0^2 \text{ (2-3)}$$

$$k_3 = \omega_0^2\omega_1 \text{ (2-4)}$$

2.3.2 High Pass Speed Channel

The motion platform pitch, yaw and roll motion will be high pass filtering channel angular velocity. Because the pitch angle and roll angle of the seat correspond to the Euler angle, the Euler angle of the moving platform coordinate system in the fixed coordinate system and the low pass filtering Euler angle can be obtained. The rolling motion of dynamic modelof the seat by a high pass filter to six degrees of freedom motion platform only respond speed high frequency response. The high pass speed channel is the two - order filter.

$$\frac{\ddot{\theta}_m}{\ddot{\theta}_i} = \frac{s^2}{s^2 + 2\delta\omega_n s + \omega_n{}^2} \text{ (2-5)}$$

2.3.3Design ofLowPassFilter

Low pass filter is mainly used for the six degree of freedom of the pitch and roll motion. In order to achieve the vertical and horizontal acceleration, the linear acceleration of the seat dynamics model will result in the increase of pitch angle and roll angle. Low pass filter in the form of:

$$\theta = \left(\frac{\omega^2}{s^2 + 2\delta\omega s + \omega^2}\right) arctan\left(\frac{\ddot{x}_i}{g}\right) \text{ (2-6)}$$

It should be noted that, in the steady state, $tan\,\theta = \ddot{x}_i / g$ where g is the gravity acceleration.That is to say, the cockpit will keep rotating until the desired acceleration is obtained. But the value will be limited to less than 1g. In addition, due to the pitching angle and roll angle of the moving platform in the Euler angle, it is not required to transform the variable to the moving coordinate system. The feedback coefficientsare k_1 and k_2 respectively.

$$k_1 = \omega^2 \text{ (2-7)}$$

$$k_2 = 2\xi\omega \text{ (2-8)}$$

III. Human Body Movement Physiology

Motion Theater mainly by the control system, motion system, visual system, sound system, etc. As shown in figure 3, The control system is the core of the proprioceptive simulation system which is used to connect the visual simulation system and the motion system, visual simulation system of vehicle environment, including runway, lighting, buildings, fields, roads, rivers, topography, visual system should be able to provide a different perspective to the driver personally on the scene feeling. Sound system to provide the driver with a variety of sound effects, sound system frequency and amplitude will also vary with the vehicle and the visual environment changes.

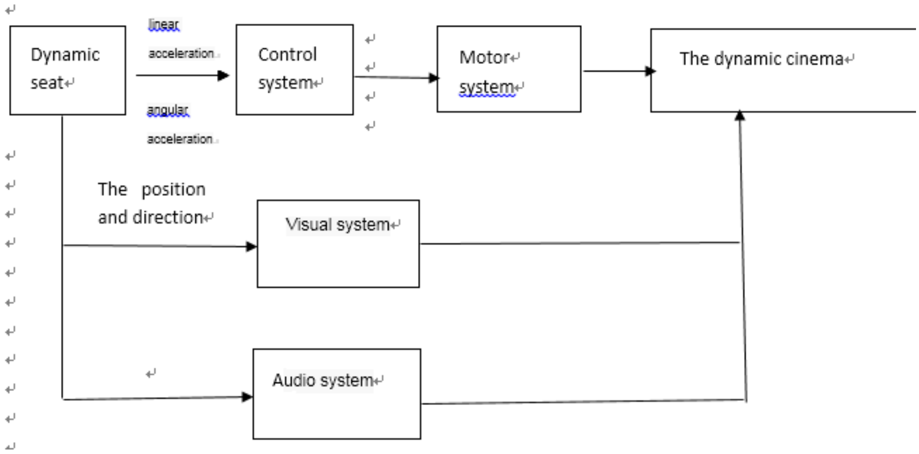

Figure 3 dynamic theater structure

In order to reproduce the real motion simulator platform in the vehicle body, we must first in the real situation of human motion understanding feelings. The human body's motion sensory system can not only feel the linear acceleration and angular acceleration, but also can detect the tactile pressure on the skin through tactile senses. The vestibular organ of the brain is combined with the eye to complete the judgment of the direction of the head and the perception of the dynamic motion. The vestibular system includesstatolith and semicircular canal. Deep understanding of human motion senses, confirming the limits of the brain's detection movement, can use this information as much as possible to reduce or simplify the movement needed to implement the simulator platform [8].

In 1974, Ormsby presented the response of semicircular canal:

$$\frac{y(s)}{\phi(s)}=\frac{0.07s^3(s+50)}{(s+0.05)(s+0.03)} \quad (3\text{-}1)$$

Among them, ϕ is the angular displacement; y is the perception of the displacement.

In order to simplify the calculation, the two order approximation is used to replace the transfer function:

$$H(s)=\frac{L\left(\hat{\omega}\right)}{L(\omega)}=\frac{T_L T_\alpha s^2}{(T_L s+1)(T_s s+1)(T_\alpha s+1)} \quad (3\text{-}2)$$

In the formula, the ω is the angular acceleration input, $\hat{\omega}$ is the feeling of the angular acceleration, T_L 、 T_s 、 T_α is the model parameters of the semicircular canals.

The eardust can detect linear acceleration, the sensor consists of a hair cell gel liquid, liquid containing calcium carbonate crystal. When the head is accelerating, hair cells can be detected by calcium carbonate crystal particles lagging slightly behind the head motion detected by the motion of hair cells of neurons, and then transmits a signal to the brain and eye muscle movement. Can set up the mathematical model of the transfer function of the eardust reaction:

$$H(s)=\frac{L\left(\hat{f}\right)}{L(f)}=\frac{k(\tau_\alpha s+1)}{(\tau_L s+1)(\tau_s s+1)} \quad (3\text{-}3)$$

In the formula, f is the external force, $\hat{f}$ is the feeling of the external force, k is gain, τ_α 、 τ_L 、 τ_s are the otolith model parameters.

In practice, the equivalent two order transfer function is usually used as the time constant of 0.66s and 10s. It is obvious that the vestibular organs of the human can detect the acceleration motion of the platform much sooner than the meter. In particular, the attitude and altitude are the two order integral of the acceleration, and the effect of the initial acceleration is introduced. It can be said that people have an internal control loop that is able to detect and make a projection of acceleration.

IV. Filter Simulation Analysis

This chapter combines the human physiology model, establish washoutfilter model by using MATLAB software, the simulation analysis of the movement of the seat.

4.1 Body Perception ModelParameter Selection

In 1966, American scientist J.L. Meiry in the book, the specific parameters of the semicircular canals and the otolith model were determined by a lot of experiments and statistical analysis, see table4-1[9].

Table 3-1 Parameters of human atria model

The model Parameters of Semicircular Canal				Otolith Model Parameters			
Parameter	Yawing	Pitching	Rolling	Parameter	Lifting	Translation	Lateral Displacement
$T_L(s)$	10.2	5.3	6.1	$\tau_L(s)$	5.3	5.3	5.3
$T_s(s)$	0.1	0.1	0.1	$\tau_S(s)$	0.6	0.6	0.6
$T_a(s)$	30	30	30	$\tau_a(s)$	13.1	13.1	13.1
δ_{TH}	0.045	0.0628	0.052	K	0.4	0.4	0.4
				$D_{TH}(m/s^2)$	0.165	0.168	0.275

4.2 Filter Parameter Selection

The parameters of the filter need to be constantly modified until it can be more realistic to simulate the motion of the aircraft. Among all the parameters, the natural response frequency is influenced by the performance of the filter, and the optimal parameter value is selected by comparing the frequency of multiple natural frequencies. Table 3-2 is the best parameter to choose after the experiment.

Table3-2 Parameters of algorithm

Passageway	Order Number	$\omega_H(rad/s)$	δ	$\omega_L(rad/s)$
Lifting	3	3.5	1	1
Translation	3	2.5	1	0
Lateral Displacement	2	3	1	0
Yawing	2	0.9	1	0
Pitching	2	0.9	1	0
Rolling	2	0.9	1	0

In order to test the characteristics of the high pass filter, set the amplitude is $1m/s^2$, the pulse width of the pulse acceleration signal respectively through the 5S as shown in Figure 5 two order and three order high pass filter after washout, As can be seen from figure 5-a, the acceleration signal after two order and three order high pass filter, analog acceleration output signal changes are small, little impact on the simulation results, and the output signal of the displacement platform is different. Figure 5-b two order output platform is a constant displacement washout filter, and the output of three order washout filter end is equal to zero, and the amplitude of the output displacement platform size are quite different.

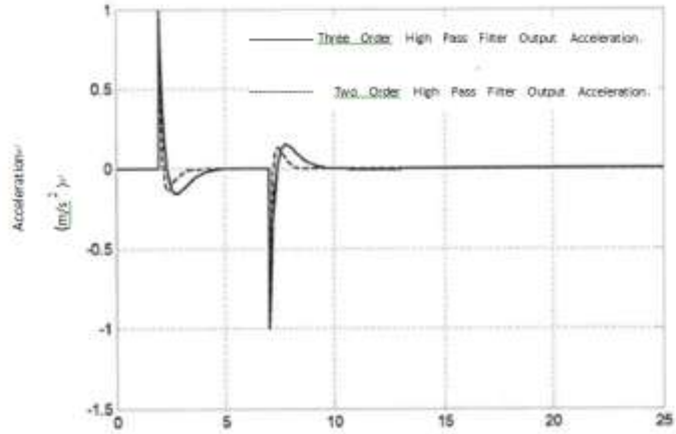

Figure5-a Output acceleration signal

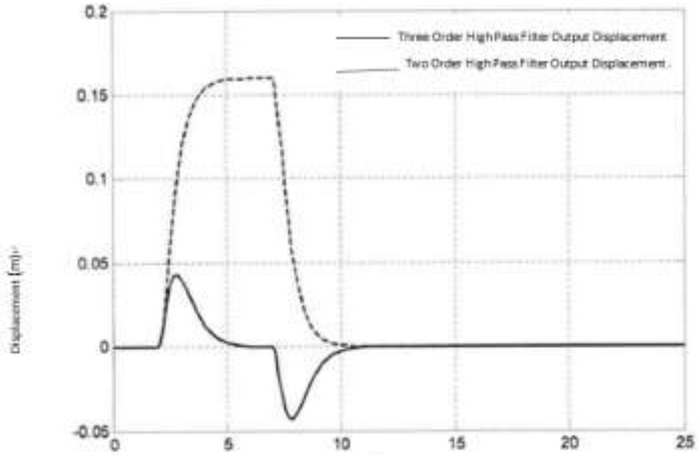

Figure 5-b Output displacement signal

After selecting the appropriate filter parameters, we can use the filter to simulate the response of the platform. In order to test the characteristics of the filter, set the unit step signal as the input angular velocity signal, after signal of one order and two order high pass filter as shown in figure 6-a, the angular displacement output platform is shown in figure 6-b, obviously the angular displacement of two order high pass filter platform will eventually return to zero. In this paper, the angular velocity of the high pass filter using two order high pass filter.

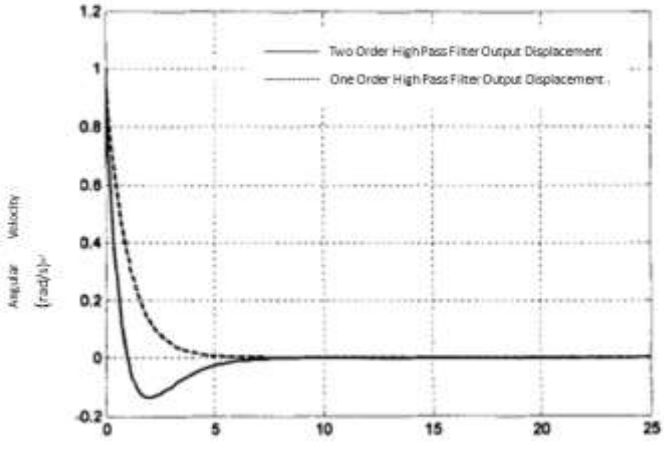

Figure 6-a Angular velocity signal

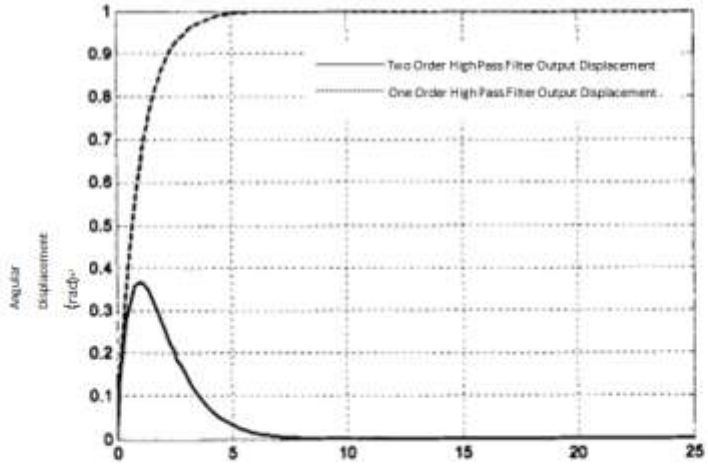

Figure 6-b angle displacement signals

V. V.Summary

This chapter according to the human physiological principle of human motion perception in-depth understanding, the model of the human vestibular as a necessary condition for recurrence movement washout algorithm model, based on the classical washout filter algorithm is designed. The perception of the six DOF motion platform control algorithm and the washout algorithm was simulated by MATLAB software. Simulation results show the correctness of the algorithm in the control platform.

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