



PERFORMANCE EVALUATION OF SIMULATED MOTION CUEING ALGORITHM OF A DRIVING SIMULATOR

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Abstract: This research presents the simulation of motion cueing algorithm for a six degree of freedom motion platform for a driving simulator. The control system design include review of different types of motion cueing algorithm, configuration, and mathematical model, development of washout algorithm, simulation and validation of the result. The design of the motion platform incorporated is based on the popularly known Stewart Platform frame work. This is modelled mathematically by inverse kinematics for controlling the legs of the driving motion platform. The platform 3D multi-body model generated using MATLAB and Simulink software is incorporated with motion cuing algorithm, this is used for visualization of responses and understanding the influence of the motion cueing algorithm. To ensure proper implementation of the algorithm on a physical simulator, several simulations were carried out resulting in the simulator platform displacement and orientation. In the washout simulations, there was return of all displacement to zero as time increases which will be regarded as successful.

Keywords: Motion cueing algorithm, mathematical model, driving simulator, performance

I. Introduction

Motion simulation is evolving rapidly as a result of development in computer and electronic technologies as well a more affordable cost of laboratory facilities compared to past decades. This research work focuses on the driving simulator and simulation. Flight, train, bicycle and other simulators are exempted in this review. The driving simulator is widely employed in different areas such as research facilitating, scientific evaluation of driver behavior, driver training and entertainment etc. Driving simulation has evolved tremendously in similar fashion to the flight simulators mainly due to the apparent development computer technologies and the idea avoiding real life procedures which are prone to heavy cost and safety risk. Generally, simulators are identified by a motion base having wide range degree of freedoms (DOF), thus the major challenge encountered in simulation is the reproduction of realistic motion cues that can conform to a real driving scenario. Some of the key advantages of simulation instead of test drives on tracks are the ability to study unexpected phenomenon in system behavior, at the same time saving cost and minimizing risk.

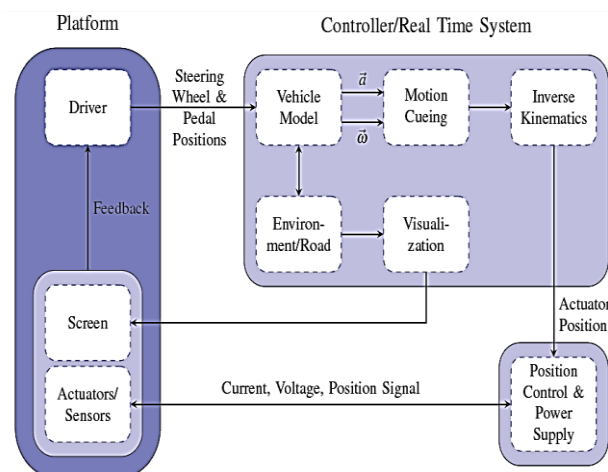


Fig. 1: Full structure of Simulator system [1].

Figure 1 depicts the structure of a complete simulator system. There are 3 major sections namely; a movable platform for vestibular cognition, a display screen for visual cognition and driver seat with steering pedals and wheels. The real time system that computes the resulting acceleration depends on input parameters and road signals of the environment for car modeling. The driver cab utilizes actual visualization of environment calculated in generation of motion cueing. This is achieved through inverse kinematics and an inverter cell with a position controller aid the leg movement to desired displacement [1].

II. Motion simulation

An imitation of a process, state of affair or something real is called simulation, while motion simulation is entirely about perception. There are two inputs meant for motion perception in the human body; environmental motion in relation to the body and inertia stimulants on the body. The inertial stimulation results from eternal force, gravitational force and moments on the body [2]. In the inner ear (right and left) is located a vestibular system. A prominent sense responsible to feed information relating to angular and linear inertial acceleration is based on the perceptual system. The sense of speed is possible through the visual system in the human body [3] and acoustic system can also acquire the sense of speed.

A. Motion cueing

Motion cueing refers to the presentation of vestibular, acoustic, haptic and visual information with the purpose of replicating real movement in a virtual environment [12]. The widely adopted method of motion cueing is classical washout filter or MDA (motion drive algorithm) [16]. Furthermore it is widely employed in six-axis motion platform called hexapod or Stewart platforms. This is required to constrain the simulator motion within the limits of the system; the principle is demonstrated in the Fig. 2.

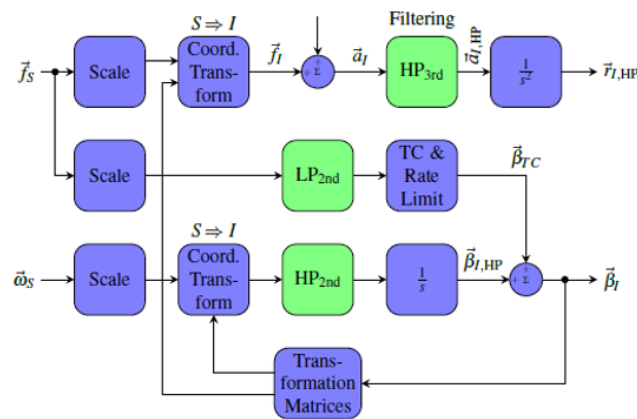


Fig. 2. Structure of classical washout filter [1]

It can be seen from Fig.2 that only high frequency component of the (on set cue) rotational and translational acceleration is replicated by the simulator [16]. Low frequency information is provided by the visual system. For lateral and longitudinal acceleration tilt coordination is utilized in replicating the sensation of continuous acceleration. Van der Steen carried out an extensive survey on motion perception, where he presented a model of self-motion perception. The acceleration felt by the driver was found to be the same as he visually perceives [2]. This is correct to a certain point; indifference zone is determined by threshold values. These values are varied as a function of degree of freedom, workload and frequency [9], but are typically determined at a maximum acceleration of $\pm 0.6 \text{ ms}^{-2}$ and angular velocity $\pm 30 \text{ ms}^{-1}$ [12]. The ability of the platform staying within this zone that is below this values, results in the platform moving without the occupant noticing the motion.

B. Adaptive algorithm

Cornelius, 2006 described adaptive algorithm to entail empirically computed combination of low and high pass filter, in other words it is an improved version of the classical washout filters which has a similarity to high pass and low pass filters. Although this is based on parameter optimization which is referred to as a non-linear system, variations of the different coefficients of the transfer function are done systematically. For instance the cut off frequency and the gain will be varied which has an impact on minimizing cost function, penalizing errors on platform acceleration and displacement constraints [5]. This method enhances realistic nature of the simulator by accommodating maneuverings sustained motion cueing, heavy braking system to be highly filtered.

C. Optimal Algorithm

The inception of optimal algorithm dates back by popular known authors work such as [18], [17]. There was an improvement on the adaptive algorithm where as “optimal control deals with the problem of finding a control law for a given system, such that a certain optimality criterion is achieved” [18]. It is a more intricate form of motion cueing where cues are closely tracked. For instance where anticipated vehicle accelerations are perceived by the motion simulator with a very minimal error within the constraints of the platform [19]. Janson also reported that in relation to flight simulators, this algorithm is like instinctive extension of adaptive algorithm although [5] its operation is similar to classical washout algorithm which will be further discussed in this research paper. This algorithm surfaces the question of the most appropriate way to transmit motion cueing in a way that maximization of correspondence in between reality and driver behavior in a simulator.

D. Predictive Washout Algorithm

This is a novel solution for motion simulation where adaption of washout algorithms to constraints of platform [7], minimizing perception error whilst staying within the limits of the platform as a result of ability to deal with multivariable constrained optimized cases. The input acceleration which are reference signals undergo a prediction format matching closely corresponded platform motion till the simulator physical limit is reached. Avoidance of false cues is maximized to ensure an equally flowing deceleration of the platform after encountering the physical limitation. This is fairly new and promising but not popularly used because of its structure which is still in the infancy stage. Its major advantage in comparison to the other algorithms mentioned above, is that it works based on the principle of reference trajectory prediction (e.g. longitudinal acceleration), the worst case or different scenario would not have to be considered in terms of tuning [8]

E. Motion platform

Motion platform are particularly common in the field of engineering for the purpose of verification and analysis of vehicle design and performance. The linking of physical motion to computer based vehicle dynamic model provides the user with the ability to experience the response of the vehicle to control input without necessity of building an expensive prototype [20]. As mentioned earlier, these different simulators utilize different degree of freedom but their report is focused on 6DOF. The motion simulator utilizes a 6DOF Stewart platform. It characterized with six hydraulic actuators connected to two bases, which permits varied sets of combined and complex displacements [20].

III. Filters

Filters as mentioned in classical washout algorithms are the most simple and widely employed algorithms in dynamic simulators; they are characterized by high pass and low pass filters where their parameters are tuned offline before operation. A survey carried out by [17], signifies the need for accurate development and tuning of the algorithm. The resultant of vehicle dynamics are translational and rotational acceleration, having in mind restriction of motion platform and modulation of original inputs are imperative for realistic simulation, which are computed by high and low pass filters as shown in the Fig. 2, the three (3) paths.

A. High pass filters

This function as an attenuator of low frequency signals, on the other hand allowing high frequency signals to pass. With a proper chosen cut-off frequency, it restricts the movement of the platform with respect to the physical limitations. The transfer function is given as

$$H_{HP,3rd(s)} = \frac{s^2}{s^2 + 2\xi W_n s + W_n^2} \frac{s}{s + W_n} \dots\dots\dots (1)$$

Where,

W_n is the cut-off frequency and

ξ is the damping ratio and s is the Laplace Operator.

To maintain acceleration, the translational and rotational signals are high pass filtered with the aid of second and third-order filters returning the platform to its initial position. It is to be noted that angular motions of the vehicle simulation with low acceleration levels are also high pass filtered although by nature they are mostly high frequency accelerations

B. Low pass filter

Low pass filter functions in opposite to high pass filters. They attenuate high frequencies while low frequencies are unchanged; the processed signals passes through the rate limiter afterwards yields pitch and roll tilt angles of the simulator.

$$H_{LP,2nd}(s) = \frac{V_n^2}{s^2 + 2\chi W_n + W_n^2} \dots\dots\dots (2)$$

IV. Choice of Motion Algorithm

After careful consideration, the chosen type of algorithm proposed for the research work is classical washout algorithm. This decision was made due to various reasons, including the fact that this simulator is built from the beginning; it is most appropriate to use an easily implementable algorithm. Nevertheless it promises high quality motion cues, for instance Table 1 shows evidence from the notable and famous work of past authors.

Table I ALGORITHM COMPARISON [17]

Algorithm	Total number of differential equations	Computation and iteration time [ms]	Number of free parameters	Transparency
Classical washout	13	1.0	21	Good
Optimal washout	24	1.3	38	Fair
Predictive washout	38	1.8	64	Fair

From Table 1, it can be seen that compared to the optimal and predictive washout algorithm, the classical algorithm has a shorter computation time, is affected by the total number of the differential equations. Furthermore, this algorithm has a good transparency, which makes its implementation easier by more efficient prediction of changes with respect to the free parameters. Although, it has a certain number of disadvantages mainly due to the usage of linear elements without the consideration of non-linear characteristics as a result of minimal understanding of the human motion perception, yielding false cues under moderate or small maneuver. All this can be tackled through introduction of certain logics to alter the characteristics of the filters under specific conditions [5], [17].

A. Motion simulation process

This flow chart (Fig.3) describes the simulation process. The first and initial step is the input signals, in this research work sin and signal builder blocks are utilized as input signals. The input signals are now transmitted to the modeled classical washout algorithm where it is filtered before passing it to the inverse kinematics, where the desired position is calculated. Next is a PID controller for limiting error then to the 3D SIMMECHANICS model for visualization.

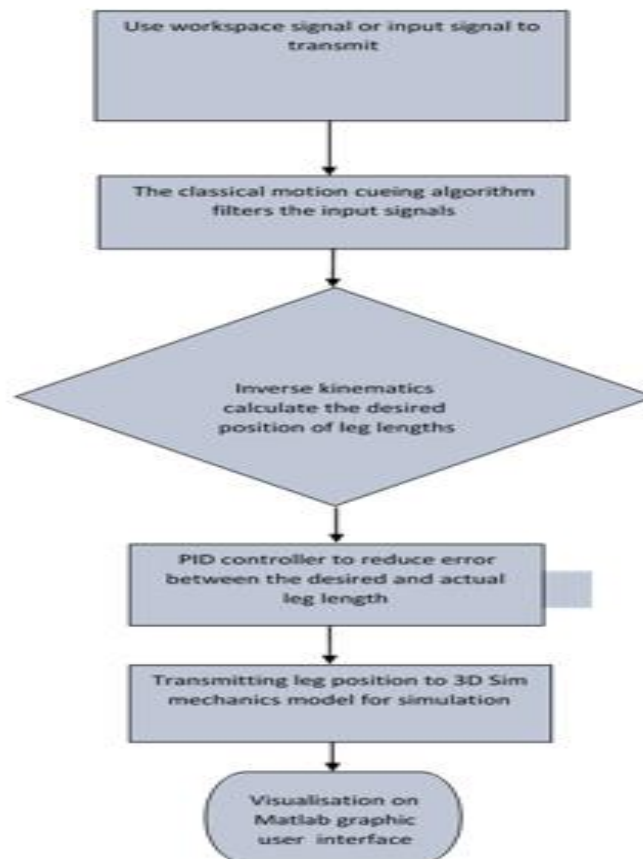


Fig. 3. Flow chart of the whole simulation process

For the visualization of the driving motion simulator dynamics, a three dimensional multi-body model was developed with the use of SIMMECHANICS blocks. This facilitates the three dimensional modeling of mechanical structures thus making visualization of simulator dynamics possible in three dimension animation. Additional SIMMECHANICS permit the import of drawn models from external software (i.e. CAD). This imported model has been modeled and assembled, after importing, the SIMMECHANICS starts the generation of a three dimensional geometry of the whole system including the all the properties as designated by the CAD software model

B. Complete Simulation model with classical washout filter

Figure 4 depicts a complete simulation model. This entails the subsystems of classical algorithm, inverse kinematics, the PID controller and SIMMECHANICS subsystem.

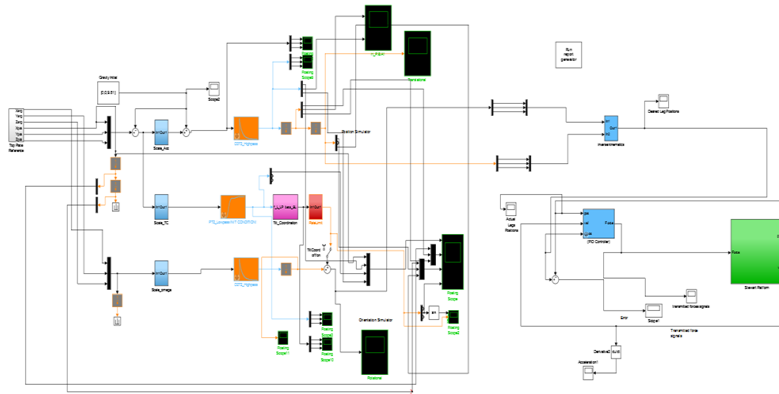


Fig. 4: Complete simulation Model with Classical washout filter.

V. Results and Discussion

A. Comparison with the two models

This section shows the comparison between the classical washout algorithm model and reference model subjected to same inputs on the save wave frequency signals as specified in Table 1, listed graph compared include the desired leg position from inverse kinematics, actual leg position, transmitted forces and motion error. Due to the limitation of the references model there was restriction in amplitudes.

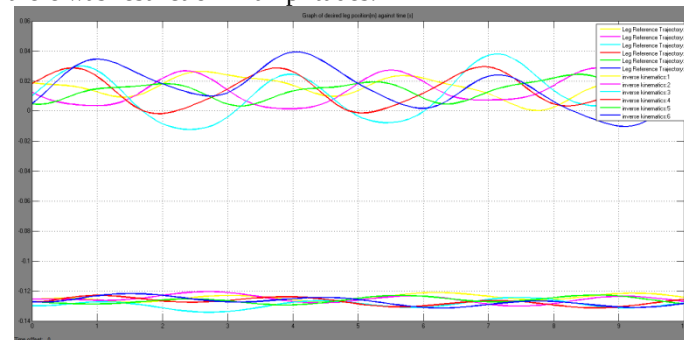


Fig. 5: Graph of desired leg position against time for 6 legs for reference model and classical algorithm model.

This shows the desired position is from the inverse kinematic of both the reference model and kinematic model.

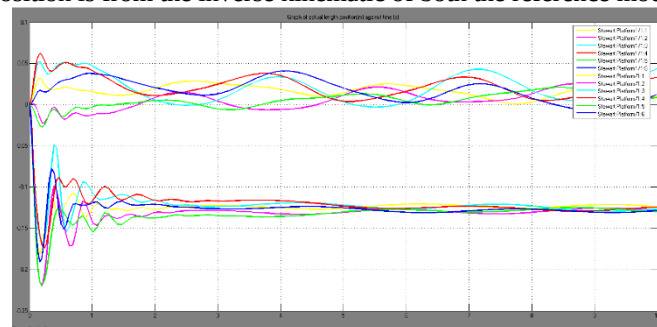


Fig. 6: Graph of Actual leg position against time for 6 legs for reference model at the top and complete model with classical algorithm below.

The actual leg position of both the reference model and classical algorithm model (Fig.6), the conformity of the classical washout algorithm is very close to the desired position. This depicts the transmitted force signals by both the reference model and the classical algorithm model. It can be seen that the classical algorithm is more coordinated, limiting the signal to the limitation of the simulator, making deliver of more force (Fig.7). Unlike the reference model the signals are not filter so it quickly reaches the maximum leg length with a lower deliver force.

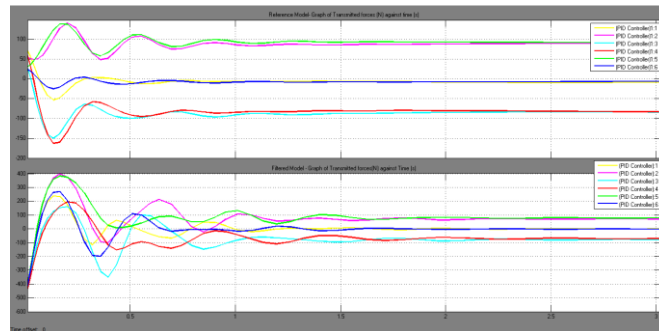


Fig. 7: Graph of Transmitted forces (N) against time (s) for 6 legs for reference model at the top and complete model with classical washout at the bottom.

From the 3D visualization interface, the leg length of reference is delivering motion at a very high position. This in turn decelerates while the filtered motion accelerates from a lower position to a maximum of 20m/s^2 .

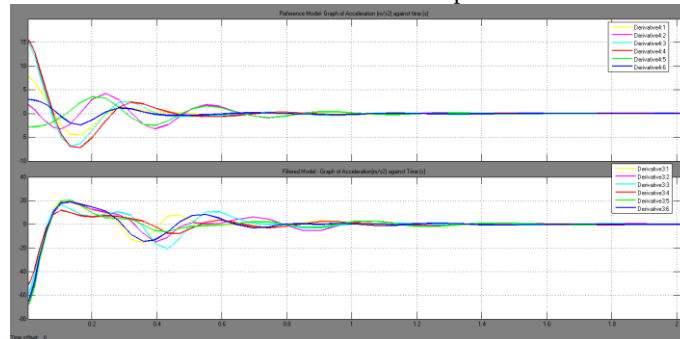


Fig. 8: Graph of acceleration (m/s^2) against time (s) for 6 legs for reference model at the top and classical algorithm the bottom.

Figure 9 depicts the position of the two model showing where they both operate; the reference model is not filtered as it renders manoeuvrings at a maximum leg length of the simulator thus exceeding the workspace while the classical washout algorithm delivers more within a limited part signifying that higher inputs signals can be transmitted within the workspace of the simulator.

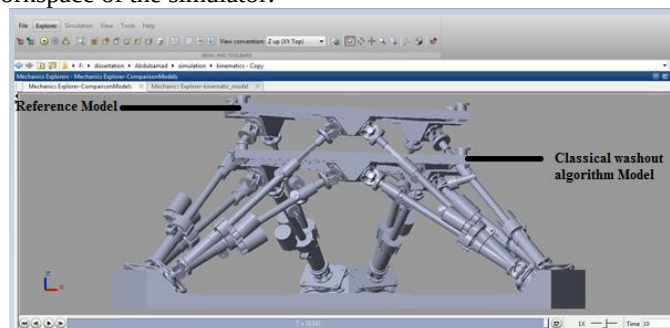


Fig. 9: A superimposed picture of both models showing the simulators position while translating motion.

B. Simulation of reference model with signal builder (higher parameter values)

In this section instead of using a sine signal blocks as inputs it is replaced by a signal builder block. The signal builder block outputs a virtual non-hierarchical bus, scalar, or array of real signals of type double [13]. In other words this represents a much bigger signal than the sine signals. As shown in Fig. 10, the reference simulator failed due to transmitted inputs signal that exceeded the limitation which lead to failure of the reference model.

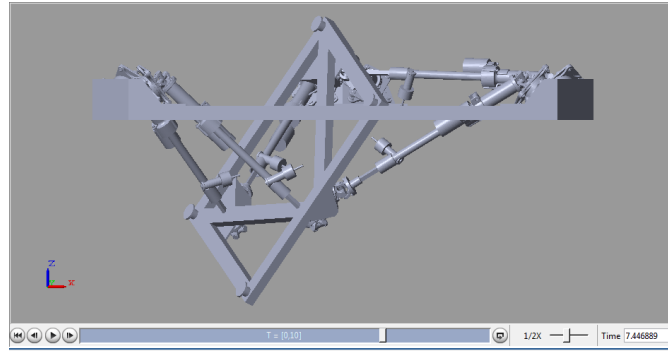


Fig. 10: Shows the reference Model subjected to higher parameter values that failed

C. Simulation of complete model with classical washout algorithm model signal builder (higher parameter values).

The model with the classical algorithm was simulated again with signal builder accelerators; A_x (Surge), A_y (sway) and A_z (sway) and corresponding angular velocities. The sine wave values were small, thus, it was done to visualise its influence on the filters. Figure 11 shows the depicts simulation result.

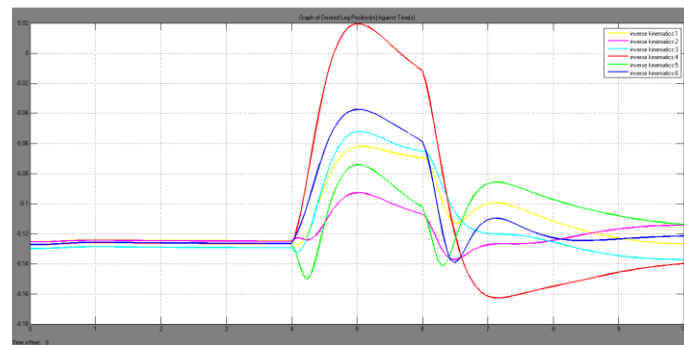


Fig. 11: Graph of desired position of the 6 legs of the motion simulator against time

As it can be seen in Fig. 12, there is a close proximity with desired leg position from inverse kinematics and translated actual position of leg lengths although there is sag in the earlier which may be related to calibration of the simulator and specific error. Actuator extension limits of 5 legs were almost same with 0.05m with exemption of the red line.

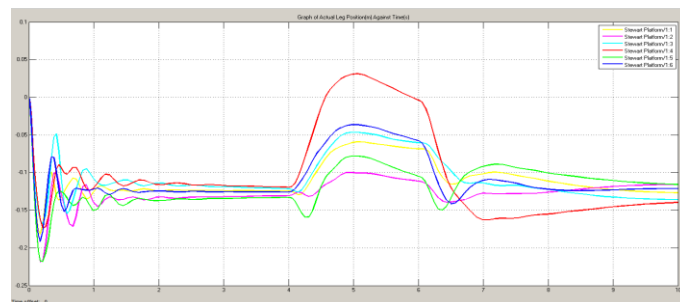


Fig. 12: graph showing the actual leg position for 6 legs against time.

From Fig. 13, a force of 400N was in both pitch angle and sways position represented by both green and purple colours.

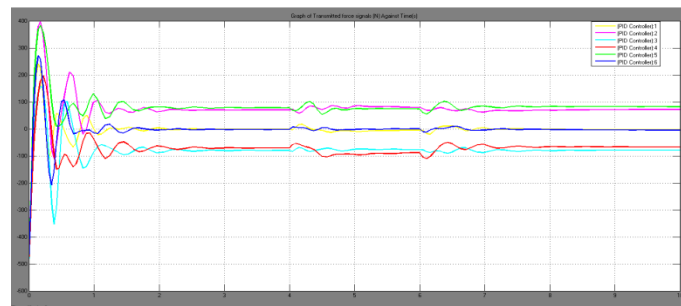


Fig. 13: Graph of Transmitted forces of 6 legs against time of 10s.

There was a rapid rise in acceleration to about 20m/s^2 then calibrates to a lower value specified by the position of the legs (Fig. 14).

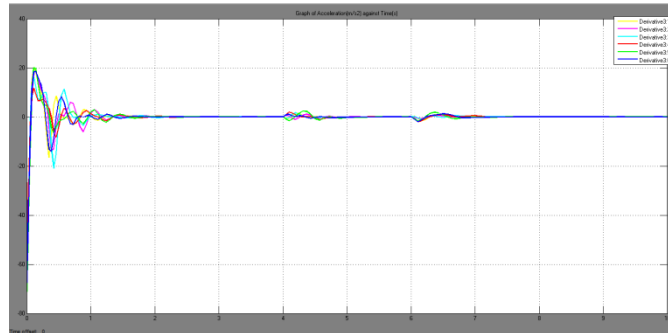


Fig. 14: Graph showing Acceleration of 6 legs against time of 10s.

VI. Conclusion

This research work is on the performance evaluation of simulated motion cueing algorithm of a driving simulator and it focuses on the classical washout algorithm for development of driving simulator. The classical washout algorithm was explained and implanted on a 3D visualization model in a SIMMECHANICS interface on MATLAB/SIMULINK to observe the features of the washout algorithm and to determine the preliminary manner of performance of the platform in different scenario. The evaluation process was carried out, a clear advantage of the different types of filters utilized. In the washout simulations it can be concluded that return of all displacement to zero as time increases which will be regarded as successful, the leg length operating below its limits.

VII. References

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