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STUDY OF THE INFLUENCE OF DIFFERENT WASHOUT ALGORITHMS ON SIMULATOR SICKNESS FOR A DRIVING SIMULATION TASK

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KEYWORDS

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ABSTRACT

This paper deals with the effects of different washout algorithms used for Stewart platforms on subjective and objective ratings. Washout algorithms are used to represent vehicle dynamics in a restricted spatial place. An adaptive washout algorithm was realized to control the hexapod platform, depending on the specific force error in longitudinal, lateral and vertical directions, in order to compare user‟s experience with those in the case of classical algorithm. In this study, the simulator sickness has been evaluated for three algorithms in dynamic driving simulator situation in objective and subjective way.

INTRODUCTION

Driving simulation is a high demanded domain in terms of virtual immersion. Compared to virtual mock-up visualization in a CAVE system, driving simulation induces the motion of the user‟s body through the car driving task. In driving simulation, the motion is mainly induced by acting on visual cue (vection process) and vestibular cue (with a motion platform). To improve the virtual immersion in driving simulation task, both cues have to be well correlated. The motion platform is controlled with an algorithm which translates the car simulated motion in a possible platform motion.

The washout algorithms are used to depict the driving dynamics of a real vehicle in a constraint space for a driving experience as realistic as possible (see Figure 2). They were firstly introduced in the mid 60s in the aerospace industry (Stewart, 1965). Afterwards, these techniques have been spread into automotive industry for the development process of the vehicles.

Different algorithms have been developed to control a 6 DOF (Degrees Of Freedom) platform (as a hexapod platform). The following table gives the list of the main common algorithms used in the literature.

Motion control algorithm	References
Classical	(Stewart, 1965)
Adaptive	(Parrish et al 1975, Ariel and Sivan 1984, Nehaoua et al, 2006 PA Ioannou and J. Sun, Robust Adaptive Control. Prentice-Hall Inc., 1995)
Optimal	(Sivan, et al., 1982)
Predictive model algorithm	(Dagdelen et al, 2009)

Objectives of the washout algorithms are given below [3]:

- Main objective for implementation of the washout algorithm is to maximize the contribution of the motion system to the capabilities of the simulator.
- Main limiting factors are the maximum speed and stroke of the actuators.
- Reproduction of motion cues one to one is not possible. Filtering and reducing cues are needed.

- The best compromise must be provided. Changing a parameter in a sense, leads to problems in another.

Cues at dynamic driving simulators are given in Figure 1. If there is a conflict between the cues, it can cause a phenomenon called „motion/simulator sickness‟.

The „kinetosis‟ or „motion sickness‟, also known as travel sickness, is a situation in which a disagreement exists between visually perceived movement and the perception by the vestibular system.

For the objective evaluation of different washout algorithms on simulator sickness, the tests were realized by using SCANeRstudio® 1.0 software of OKTAL Company with the "Country Road" scenario.

Results show that an adaptive algorithm provides a less possible opportunity to have simulator sickness, objectively as well as subjectively by using simulator sickness questionnaire.

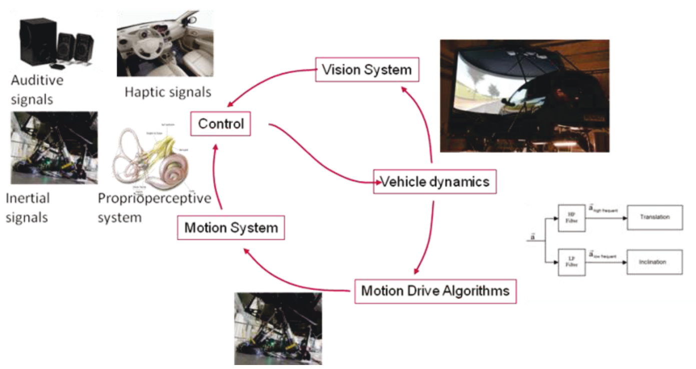

Figure 1. Structure of the closed loop control of dynamic driving simulator

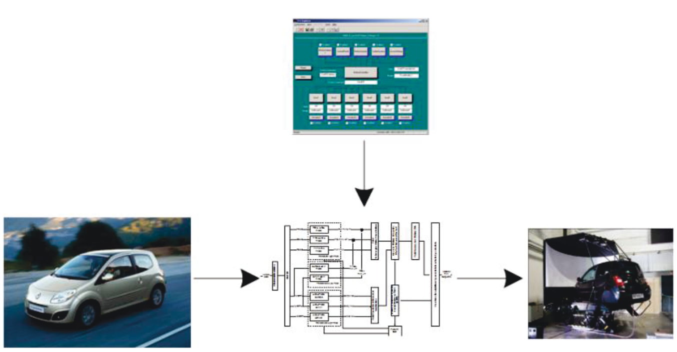

Figure 2. Objective of washout algorithm [3]

DRIVING SIMULATORS

Virtual reality environments are used more and more in engineering systems to develop and enhance product design [2]. Driving simulators are one of the widespread used types of virtual reality systems. We can distinguish dynamic simulator (with motion platform technology) and static simulator.

As stated in the Figure 1, a dynamic driving simulator is made up of the elements listed below:

- Motion system (6 DOF (degrees of freedom) hexapod platform)
- Visual system (through video projectors)
- Vehicle dynamics: vehicle model used in the driving simulation
- Motion driving algorithms (motion cueing and washout algorithms)
- Control: according to HMI (human machine interface) theory, not only the washout algorithm itself but also the driver has an important role for the control of the *driving simulation* in the scenario [4]. Driver is involved in the simulation process due to his/her reactions which are sourced from his/her "proprio-perceptive" and "vestibular system" that also enables him/her as „a second closed-loop controller‟, apart from the existing adaptive washout algorithm or vehicle dynamics controller (primary control). The correction inputs of the conductor are generally affected of those listed below:

  1. Visual signals
  2. Auditive signals
  3. Haptic signals
  4. Inertial signals
  5. Proprio-perceptive and Vestibular system

The most crucial difficulties that can be encountered in the driving simulator applications, to have a more realistic driving simulation, are:

- To embody the dynamics reaction of the driver‟s (as it is associated with the secondary closed-loop control)
- To represent the driving dynamics as in real world in the dynamic driving simulator (it is called washout algorithm) in terms of user‟s perception.

SIMULATOR SICKNESS

"Simulator sickness" is a phenomenon to define a situation in which the visually perceived movement and the perception of the movement by the vestibular system does not correspond to each other, in other words they disagree.

There are four broadly accepted theories to describe the "simulator sickness" phenomenon [2]:

- Cue Conflict Theory (Money 1970, Casali 1986, McCauley and Sharkey 1992)
- Rearrangement Theory (Reason & Brand 1975)
- Postural Instability Theory (Kolasinski et al 1994, Jones et al 1993)
- Reflex Theory (Howard, 1986; Robinson, 1981)

The factors that can cause simulator sickness may be organized in three categories [2]:

a) Individual (for example: age (Reason & Brand 1975), concentration level (Regan 1993), simulator adaptation (experience with simulator) (Uliano et al 1986, Kennedy & Frank 1983, Regan 1993))
b) Simulator technology (for example: motion platform) (Casali 1986, Kennedy et al 1987, Kennedy et al 1993, McCauley & Sharkey 1992),
c) Task (for instance: application type) (McCauley & Sharkey 1992)

MODELLING OF CLASSICAL ALGORITHM

Classical washout algorithm was introduced by Stewart in 1965 to figure out the motion cueing algorithms of hexapod motion platform (6 DOF- degrees of freedom-). The classical algorithm is also known as Stewart platform and has been firstly developed for the aerospace domain (flight simulators).

Apart from this, the usage range has been spread also to broader application areas, such as automotive to develop land vehicles.

The main objective for implementing the washout algorithm is to use the motion system as best as possible to restitute a good perception of driving situation from user"s point of view. Figure 3 shows the working scheme of the classical algorithm which was developed for our work (for 6 DOF, it consists of the lateral and vertical dynamics and the corresponding inclinations, tilts, as well as the longitudinal shown in Figure 3).

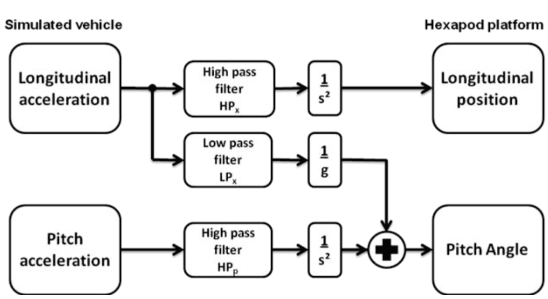

Figure 3. Schematic of the classical washout algorithm

MODELLING OF ADAPTIVE ALGORITHM

Parrish and al [10] provided motion cues which can be seen as a classical one where parameters are variable and calculated at each step of simulation time.

Various schemes were proposed to improve the stability of algorithm [11]. Ariel and Sivan [7] include the vestibular system for the lateral false cues reduction. It is based on the minimization of a cost function containing the acceleration error and constraints on the platform displacement. The adaptation is carried out using the „Steepest Descent Method" to resolve the sensitivity equations [6, 8]. The resulting filter is then nonlinear. The operating scheme of that adaptive motion cueing algorithm has been given below in Figure 4.

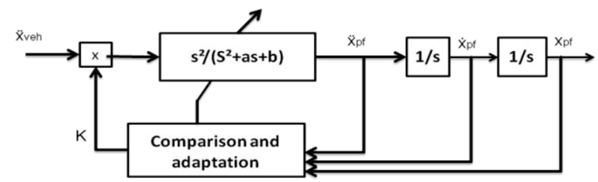

Figure 4. **Schematic of the adaptive washout algorithm**

The filter equation is given by:

$$\ddot{x}_{pf} = K \cdot \ddot{x}_{veh} - a \cdot \dot{x}_{pf} - b \cdot x_{pf} \quad (1)$$

$\ddot{x}_{veh}$: Virtual vehicle acceleration

$\ddot{x}_{pf}$: Platform acceleration

$\dot{x}_{pf}$: Platform velocity

x_{pf} : Platform position

K , a and b are the parameters of the washout filter.

To control the platform motion based on the adaptive washout algorithm, the cost function to be minimized is given in equation (2)

$$J = \frac{1}{2} \cdot \left[\omega_a \left(\ddot{x}_{veh} - \ddot{x}_s \right)^2 + \omega_v \dot{x}_s{}^2 + \omega_p x_s{}^2 + \omega_{pi} \left(P_i - P_{i0} \right) \right] \quad (2)$$

where ω_i are weighting coefficients, P_i with i = 1,2,3 are adaptive parameters and P_{i0} , i =1,2,3 are its initial values.

Optimization is realized by the steepest descent method as followings:

$$\dot{P}_i = -\gamma_i \cdot \frac{\partial J}{\partial P_i} \quad (3)$$

Once the weighting of the function cost ω_i and initial conditions P_{i0} are determined, the resolution of sensitivity equation enables the determination of acceleration and position signals to drive the platform.

One problem of this algorithm is the stability of the gradient descent method. This is related strongly with the parameters of adaptation which define the convergence speed of algorithm.

Figure 5 points out the simulation results of adaptive and classical washout algorithms responses together to a step input for longitudinal acceleration of 1 m/s^2 with duration of 4 seconds for a 1 DOF system.

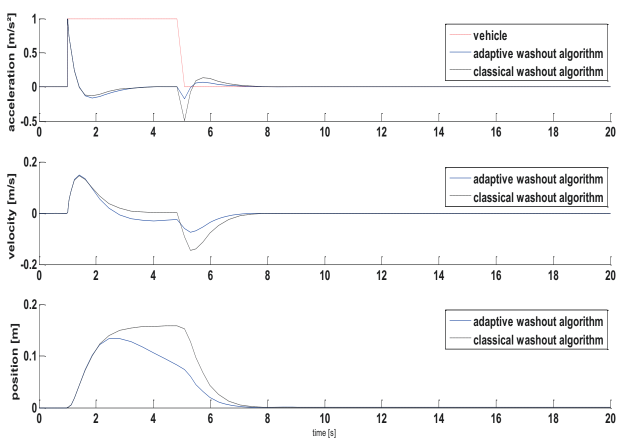

Figure 5. Classical and adaptive washout algorithm comparison of a step input for 1 DOF

VEHICLE SYSTEM DYNAMICS EMBEDDING IN DRIVING SIMULATOR

Driving simulators nowadays find application areas intensively at both research and production, because of their capability to offer a realistic environment for the driver. In Figure 6, a Man In the Loop (MIL) system has been indicated that had been utilized for these attempts.

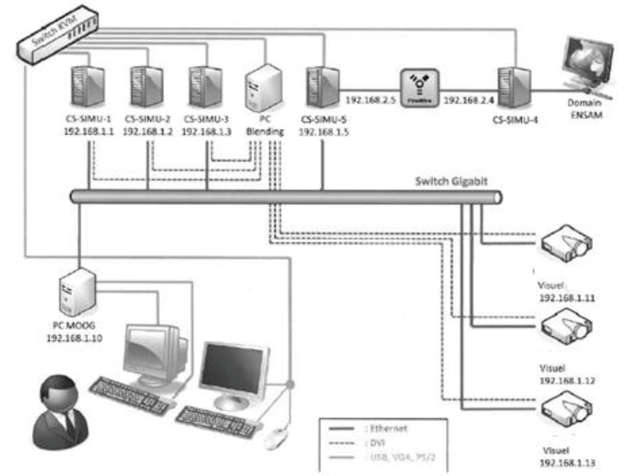

Figure 6. Networking of dynamic simulator

The operating structure of the dynamic simulator, given in Figure 6, is made up of five main components:

1- Master Computer (Supervision) (CS-SIMU-5)
2- Motion Control Computer (PC MOOG)
3- Driving Simulator
4- View Computers (slave PCs)(CS-SIMU-1, CS-SIMU-2, CS-SIMU-3)
5- Video projectors for the left, centre and right visuals.

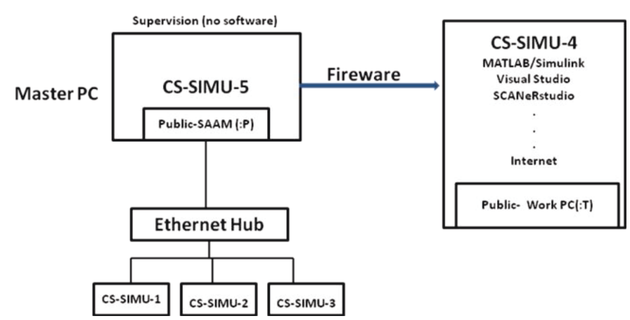

Figure 7. Connection of the PCs of the simulator

As seen in Figure 7, Host (master) computer contains vehicle types, driving maneuvers, driving environment, animator and vehicle dynamics which are included in SCANeRstudio. In addition to this, the host has access to work PC shown as CS-SIMU-4 in Figure 7 for communication interfaces, for control displays and to specify the vehicle coordinates.

Additionally it includes interfaces for the driving simulator (for Gas/Brake pedals Analog I/O and for steering wheel CAN Bus Interface and also Sound interface for the sound system).

Motion control computer (PC MOOG in Figure 6) is the element to control the position and orientation of the Stewart platform. Kinematics and dynamics of the platform are manipulated by PC MOOG. This component accomplishes motion algorithms and washout as well as position velocity acceleration (PVA) transformations.

Driving simulator is constituted of four elements and the driver in the loop:

1- Control system: Steering wheel, gas pedal, brake pedal (haptic cues)
2- Sound system (acoustic cues)
3- Motion system: Hexapod platform (inertial cues)
4- View system: 3 channel animator view in the driver‟s cabin.(visual cues)
5- Driver (proprio-perceptive,vestibular system)

TESTS ON DRIVING SIMULATOR

In this study, the simulator sickness has been evaluated objectively and subjectively on driver in the dynamic driving simulator SAAM in function of three different motion platform algorithms. The SAAM simulator has been designed and developed by Arts et Métiers ParisTech and RENAULT. For the objective evaluation, we used the data acquisition from the SCANeRstudio® to collect the data related to commands (steering wheel angle, accelerator, brake pedal force, etc.), dynamics (vehicle dynamics data), engine, motion platform (position in X, Y and Z axis and the angles around X, Y and Z axis). The Table 1 gives the capabilities of the driving simulator SAAM we used.

Table 1: Software limits for each degree of freedom (DOF) of the dynamic simulator SAAM [MOOG FCS User Manual]

DOF	Displacement	Velocity	Acceleration
Pitch	±22 deg	±30 deg/s	±500 deg/s^2
Roll	±21 deg	±30 deg/s	±500 deg/s^2
Yaw	±22 deg	±40 deg/s	±400 deg/s^2
Heave	±0.18 m	±0.30 m/s	±0.5 G
Surge	±0.25 m	±0.5 m/s	±0.6 G
Sway	±0.25 m	±0.5 m/s	±0.6 G

The subjects were asked to drive the three different washout algorithms on the dynamic driving simulator SAAM (Figure 1) at the same scenario of Country Road of SCANeRstudio® OKTAL (Figure 8 and 9) with a constant driving velocity of v= 70 km/h. 7 subjects participated to the experiment. In addition, they had a familiarization drive before each session to avoid misevaluation and to help them assess as objective as possible.

During the testing phase, they drove three times for each motion algorithm. After each attempt they were asked to fill in the regarding questionnaire for the subjective rating of the "simulator sickness" and to evaluate the "simulator fidelity" respectively. Besides, at each essay, the data recorded with the default value of SCANeRstudio® software for sampling period of 0.1 s. [OKTAL SCANeRstudio User Manual]

Figure 8. Country scenario OKTAL SCANeRstudio [OKTAL SCANeRstudio User Manual]

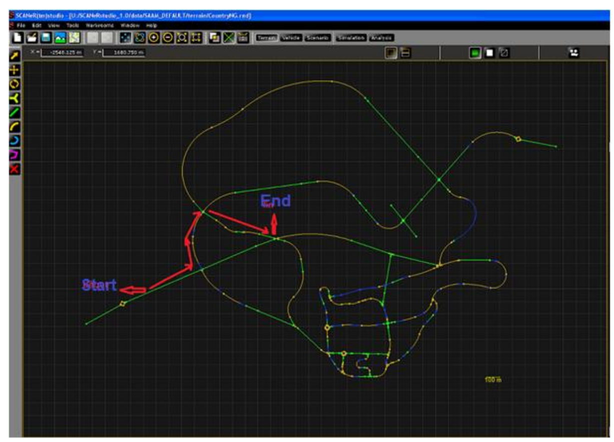

Figure 9. Conducted route [OKTAL SCANeRstudio User Manual]

To rate the simulator sickness, the "simulator sickness questionnaire (SSQ)" (Kennedy 1993), "motion sickness questionnaire (MSQ)" (Kennedy 1992), "biofeedback methods (BFM)" are commonly applied with some other approaches like "motion sickness dose value (MSDV)" (ISO 2631-1, 1997) (Griffin 1990).

OBJECTIVE EVALUATION

Objective evaluation refers to an assessment method for the driving simulator applications of which the measured data such as the effective roll, pitch, yaw angles of the hexapod motion platform; positions of the motion platform ; the dynamics data of the vehicle model, etc. are considered.

Table 2 indicates the experimental conditions of the moving base simulator experiments.

Table 2: Conditions of the moving base simulator experiments

Classical Washout Algorithm	Adaptive Washout Algorithm (adaptive1, scale factor: 0.2)		Adaptive Washout Algorithm (adaptive2, scale factor: 1.0)	
Velocity	Travel Scale factor	Velocity	Travel Scale factor	Velocity
70 km/h	0.2	70 km/h	1.0	70 km/h

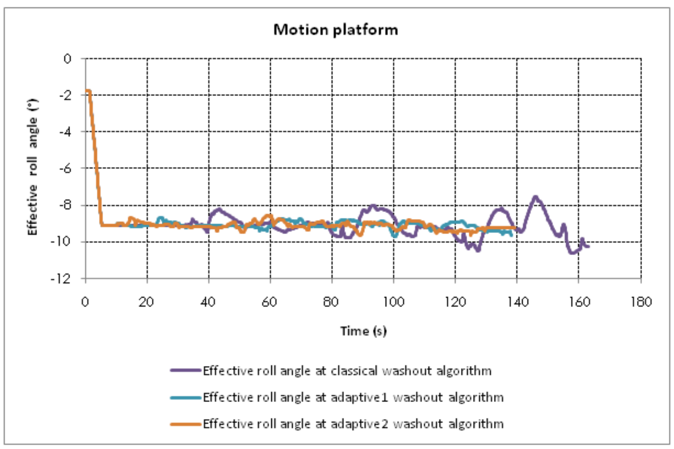

Figure 10. Effective roll angle of the motion platform at different motion drive algorithms

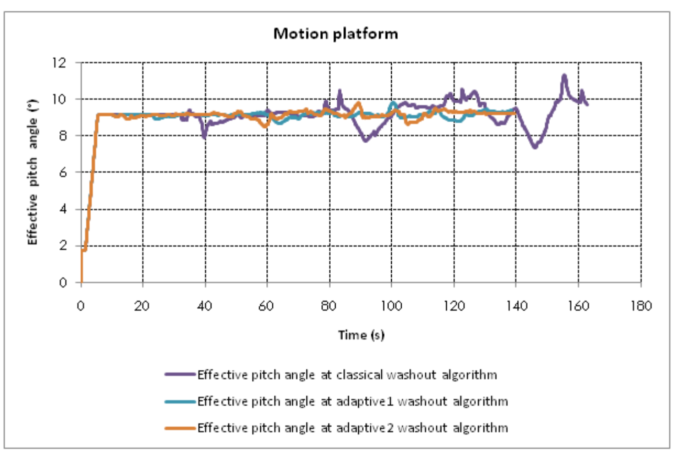

Figure 11. Effective pitch angle of the motion platform at different motion drive algorithms

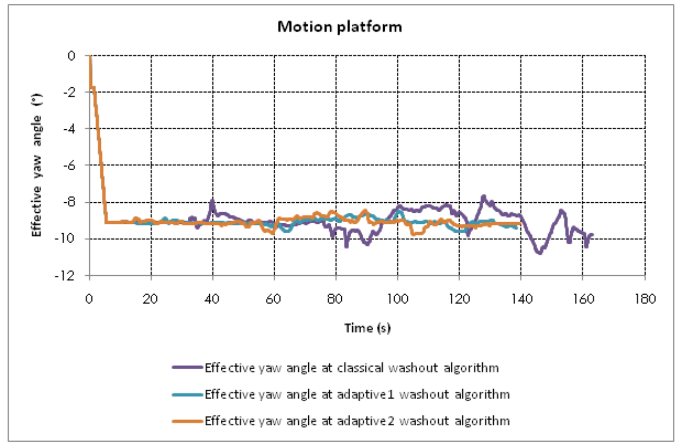

Figure 12. Effective yaw angle of the motion platform at different motion drive algorithms

The results from the motion platform (Figure 10, 11 and 12) point out that by increasing the travel scale for longitudinal, lateral and vertical axis of the hexapod; the oscillations of the associated rotation are being more smoothed. It means that the greater the travel scale factor on the adaptive washout algorithms commanded platform dynamics is, the less the undulations will occur.

EFFECT OF THE DRIVER AS A CLOSED LOOP CONTROL

As we discussed above, the subject participating in the experimentation is also a secondary closed loop controller in addition to washout algorithm. In fact, the subject can also be considered as a primary control (we have investigated the primary control as open loop „classical washout‟ and as closed loop „adaptive washout‟ in this paper).

The lateral position difference of those which have been obtained from the driving simulator („driver + washout algorithm‟ as controller, see blue curve below) and the simulation („washout algorithm‟ as controller, see red curve below) results figure out that, even the same scenario with the same washout has been realized, the results have differed to each other which emphasizes the factor of the „driver behavior‟ that is probably the most difficult part to model, estimate and/or simulate to capture a better fidelity for driving simulator research and development phases.

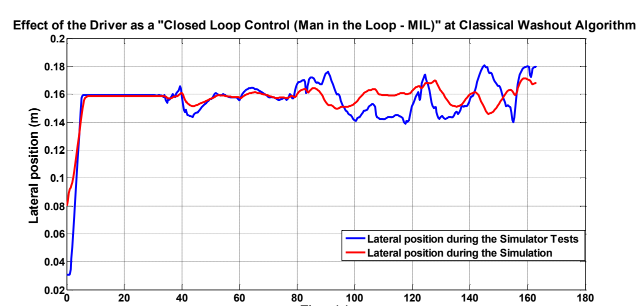

Figure 13. Driver's influence as a second closed loop controller

OBJECTIVATION OF SUBJECTIVE EVALUATION: 'MOTION SICKNESS DOSE VALUE'

"Motion Sickness Dose Value" is a method for the objectification of subjective evaluation which has been defined in accordance of ISO 2631-1 1997 (Griffin 1990) which we proposed also in this study for the same purpose. In this work, we propose to use this evaluation method and use the following function to evaluate the motion sickness dose value.

$$MSDV_z = \left[\int_0^t a_{zwf}^2(t) \cdot dt \right]^{0.5} \left[m/s^{1.5} \right] \quad (4)$$

$MSDV_z$: Motion sickness dose value for vertical dynamics (ISO 2631-1 1997) [$m/s^{1.5}$]

a_{zwf} : weighted vertical acceleration [m/s^2]

The equation above points out the vertical dynamics related to „motion sickness dose value".

With this analogy, the MSDV can be expanded for roll and lateral acceleration to assess the motion sickness dose value sourcing from the roll and lateral dynamics within the dynamic driving simulators.

Illness Rating (IR) deduced from MSDV, is the following function:

$$IR = 1/50 \cdot MSDV_z \quad (5)$$

According to the yielded results, the subject is prone to be defined in terms of his/her illness scores as "0,1,2,3" as follows:

0 = I felt good,
1 = I felt a mild illness
2 = I felt very bad.
3 = I felt absolutely terrible.

OPTIMIZATION OF SIMULATOR SICKNESS

To prevent and/or avoid the simulator sickness, a method is proposed illustrated in Figure 14.

According to the sickness reduction logic (SRL), three different washout algorithms (classical, adaptive 1, adaptive 2) were embedded in the driving simulation software SCANeRstudio of OKTAL as „dll plugin" which is also capable of configuring as well as changing the motion cueing strategy externally.

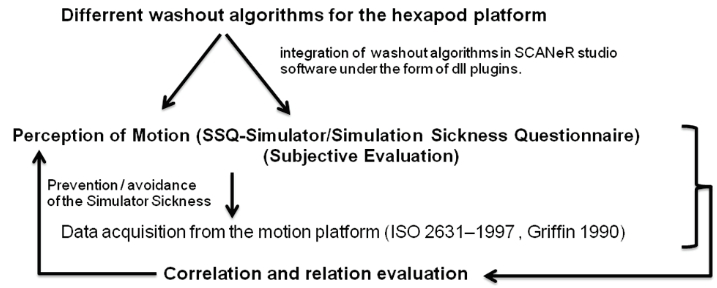

Figure 14. Proposed procedure to reduce the sickness on simulator (Sickness Reduction Logic -SRL-)

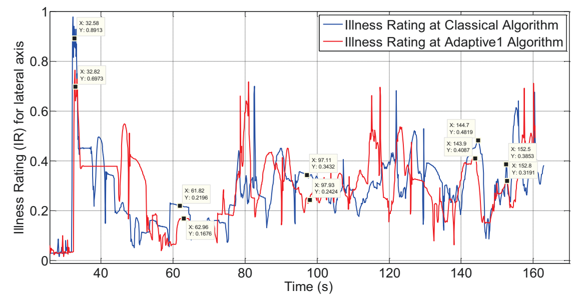

Figure 15. Illness rating related with lateral dynamics by V_x = 70 km/h at different washout algorithms

Table 3: Peak Values of IR by means of motion drive algorithms

	Peak values by classical washout algorithm				
Evaluation steps	**point 1**	**point 2**	**point 3**	**point 4**	**point 5**
Time (s)	32.58	61.82	97.11	144.7	152.5
Illness Rating per lateral axis (Y-axis)	0.8913	0.2196	0.3432	0.4819	0.3853
	Peak values by adaptive1 washout algorithm				
Evaluation steps	**point 1**	**point 2**	**point 3**	**point 4**	**point 5**
Time (s)	32.82	62.96	97.93	143.9	152.8
Illness Rating per lateral axis (Y-axis)	0.6973	0.1676	0.2424	0.4087	0.3191

Table 4: Optimization of IR by means of motion drive algorithms

Optimization of illness by steps					
Evaluation steps	**point 1**	**point 2**	**point 3**	**point 4**	**point 5**
Percentage of optimization	≈21.77	≈23.68	≈29.37	≈15.19	≈17.18

Table 3 shows results of evaluation of test data that have been conducted on Country road scenario with classical and adaptive washout algorithms. The tests were done at 70 km / h.

Five points were taken into account to compare the behavior of the lateral dynamics of the Stewart platform, and discuss the effect of each. The values of disease ratings for each were selected in Figure 15.

The optimization of simulator sickness was provided at these five points by converting the control algorithm of the platform: instead of conventional algorithm using adaptive algorithm has an improvement of about 21.8%, 23.7%, 29.4%, 15.2% and 17.2% respectively.

SUBJECTIVE EVALUATION TESTS

The driving attempts were accomplished on SAAM driving simulator located at Institute Image, Arts et Métiers ParisTech in Chalon-sur-Saône. The Figure 16 shows the subjects age and driving experience descriptive statistics.

Relating to this subjective assessment of the simulator sickness, the driving simulation experiment used a 6 DOF (degree of freedom) motion system made up of the hexapod system (Stewart platform). The subjective evaluation tests, given in Table 2, have been realized with 7 test people aged between 25 and 42 years old and at least 6 years of driving experience. The tests were accomplished in different conditions with Country Road Scenario at constant driving velocity v=70 km/h:

- Classical washout algorithm
- Adaptive 1 washout algorithm
- Adaptive 2 washout algorithm

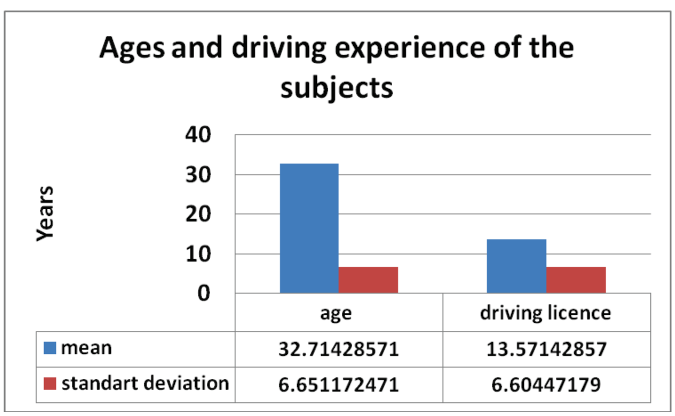

Figure 16. Ages and driving experience of the subjects

In order to assess the driving simulator tests subjectively on behalf of simulator sickness, a simulator sickness questionnaire which consists of twelve questions (notes 0: too little → 10: too strong) was proposed to each participant to have an opinion about the influence of different motion washout algorithms on simulator sickness. Figure 18 shows the mean value for the subjective rating of the sickness, whereas the Figure 19, 20 and 21 imply the statistically post-processed sickness values with confidence interval of 95%. According to Figure 18, the means of the rating for adaptive2 and adaptive1 algorithms were acquainted less than those which were obtained for the classical algorithm, as expected. However, for some questions the difference is very weak. In order to come up to a conclusion and to make a stronger statement at those points, it would be advantageous to evaluate also the subjective rating of the dynamics (simulator fidelity questionnaire, Table 6) of the dynamic driving simulator simultaneously.

Figure 17. Operating of the dynamic driving simulator SAAM

Table 5: General information about the participated subjects

Age	between 25-42 years old
Driving experience	between 6-22 years old
Class of driving licence	class A : 1, class B : 6
Earlier experience with static simulator	yes : 6, no : 1
Earlier experience with dynamic simulator	yes : 4, no : 3

The questions concerning the simulator sickness that were asked just after completion of each essay are the following ones:

Q1 - Have you vomited?
Q2 - Did you feel nausea?
Q3 - Have you had a cold sweat?
Q4 - Did you feel dizzy?
Q5 - Did you feel eyestrain?
Q6 - Did you have eyes trouble?
Q7 - Have you had headaches?
Q8 - Did you feel mental pressure?
Q9 - Did you fear?
Q10- Were you bored?
Q11- Were you tired?
Q12- Did you feel anxiety (uneasiness)?

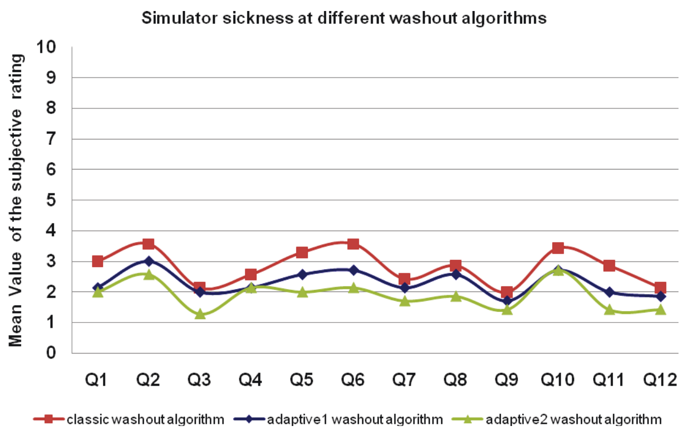

Figure 18. Subjective evaluation of the different washout algorithms in terms of simulation sickness as mean value

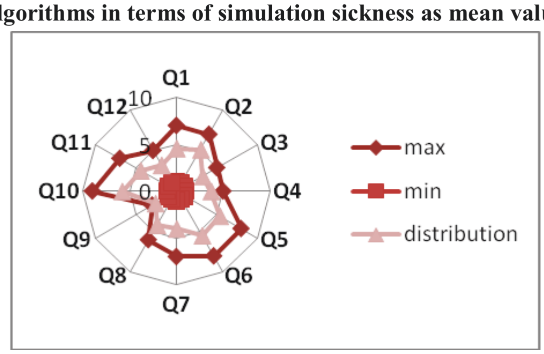

Figure 19. Statistical distribution of Subjective evaluation by means of simulation sickness at classical washout algorithm with confidence interval 95%

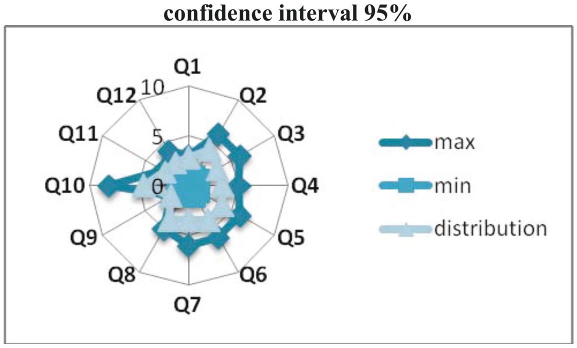

Figure 20. Statistical distribution of Subjective evaluation by means of simulation sickness at adaptive1 washout algorithm with confidence interval 95%

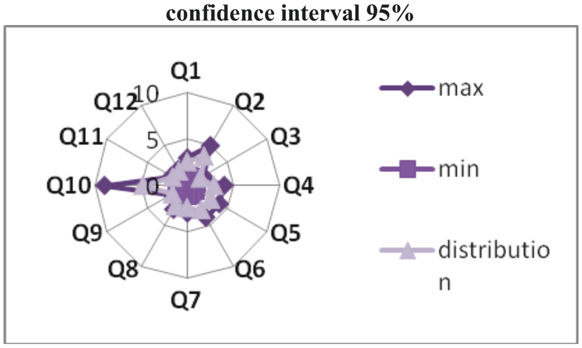

Figure 21. Statistical distribution of Subjective evaluation by means of simulation sickness at adaptive2 washout algorithm with confidence interval 95%

The questions concerning the subjective evaluation of the Simulator Fidelity (SF) that were asked just after completion of each essay are the following ones:

Q1 – How do you evaluate the visual information?
Q2 – How do you evaluate the acceleration information?
Q3 – How do you evaluate the steering feeling?
Q4 – How do you evaluate the braking information?
Q5 – How do you evaluate the roll motion?
Q6 - How do you evaluate the pitch motion?
Q7 – How do you evaluate the impression of „go ahead"?
Q8 - How do you evaluate the impression on curvature?
Q9 – How do you evaluate the simulator fidelity as whole?

Table 6: Notes for the Subjective Evaluation of SF

Q1	0: very bad → 10: very good
Q2	0: very bad → 10: very good
Q3	0: very unpleasant → 10: very pleasant
Q4	0: very bad → 10: very good
Q5	0: too little → 10: too strong
Q6	0: too little → 10: too strong
Q7	0: very bad → 10: very good
Q8	0: very bad → 10: very good
Q9	0: very bad → 10: very good

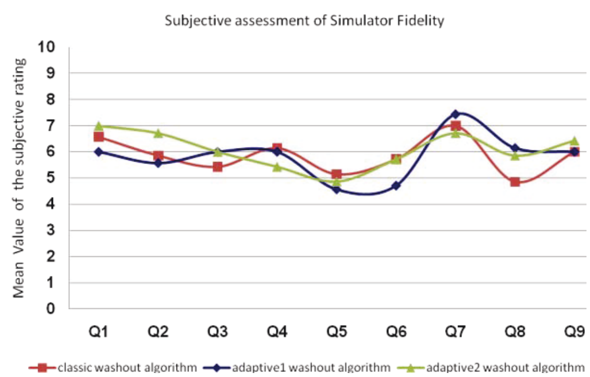

Figure 22. Subjective evaluation of the different washout algorithms in terms of SF as mean value

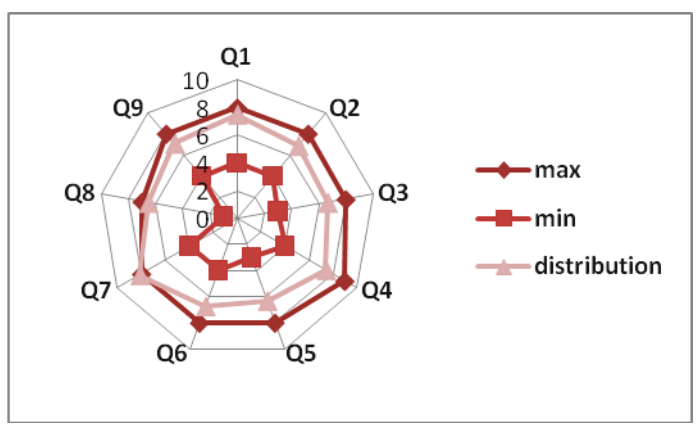

Figure 23. Statistical distribution of Subjective evaluation by means of SF at classical washout algorithm with confidence interval 95%

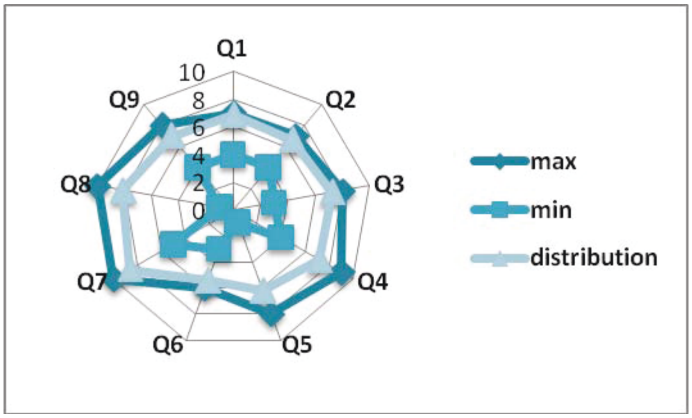

Figure 24. Statistical distribution of Subjective evaluation by means of SF at adaptive1 washout algorithm with confidence interval 95%

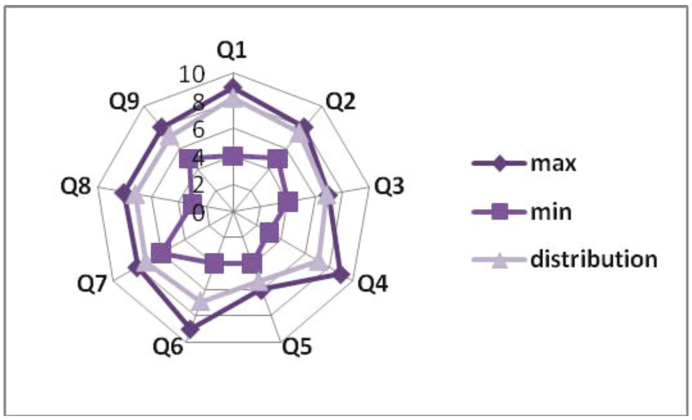

Figure 25. Statistical distribution of Subjective evaluation by means of SF at adaptive2 washout algorithm with confidence interval 95%

CONCLUSION AND FUTURE WORKS

After the research and implementation stage within the moving base driving simulator SAAM, the use of an adaptive washout algorithm has provided a reduced MSDV. It has been obtained with the help of the correction effect of the closed loop adaptive washout algorithm with respect to the classical algorithm which is an open loop one (see Figure 15, Table 3 and 4). More, these good results have been obtained with the same subjective fidelity between the three evaluated algorithms.

According to Q3 in the simulator sickness test, by the adaptive2 algorithm; the subjects reacted less stressfully (cold sweat) to the conditions, whereas they behaved more stressfully in the conditions of the classical algorithm. Regarding the visual sickness (Q5, Q6) of the participants, the adaptive2 algorithm presents the most reasonable situation.

Also concerning the mental pressure, the statistical distribution points out an agreeable experience for adaptive2 algorithm compared to the others. (See Figures 18,19,20 and 21). Based upon the „simulator fidelity assessment‟ (see Figure 22,23,24 and 25), the most realistic acceleration was perceived by adaptive2 algorithm; where the most unpleasant steering was coincided by classical; whereas the most agreeable condition was experienced by adaptive1 algorithms for perception of the pitch motion severity. The perception on curvature was evaluated the most disagreeably during the attempts with classical washout algorithms.

As a conclusion closed loop control of the platform can reduce effect on simulator sickness. For future work, we will evaluate the simulation sickness with different scenarios, like double lane change maneuvers, with different controllers. Such tests would be interested because of its high dynamic characteristics (instationary behavior). The evaluations were done with 7 subjects. In our future works, we want to improve the obtained results with more subjects. Another part of our work will be focused in the objective evaluation on the subject in order to evaluate simulation sickness. For that, we intend to make some physiological measurements (heart pulse, eye movement, eeg). In parallel to these evaluation research on simulation sickness, we work on technologies for reducing the simulation sickness (improvement of 3D sound coupled with image, vibrations on the seat) as well as studies relative to simulation sickness in static simulator (for low cost systems).

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