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The Correlation Model of Head Roll and Lateral Acceleration during Curve Driving via Hammerstein-Wiener

Sarah 'AtifahSaruchi*, Mohd Hatta Mohammed Ariff, HairiZamzuri, Nurhaffizah Hassan,Nurbaiti Wahid, Noor Jannah Zakaria

Abstract*: Generally, passengers are more prone to Motion Sickness (MS) than the drivers. The difference of their severity level of MS is due to their different head movement towards the direction of the lateral acceleration. During cornering, the passengers tend to tilt their heads according to the direction, while the drivers tends to tilt their head opposite to the direction. Based on this fact, the passengers are able to reduce their MS level if they can imitate the driver's head movement or lessen their head tilt angle towards the direction of the lateral acceleration. However, it is easier to design MS mitigation method based on the head tilt movement strategy if the mathematical expression of their head behaviour is known beforehand. On way to derive the mathematical expression is by modelling the relationship between the occupant's head tilt movements and the vehicle's lateral acceleration during curve driving. Therefore, this study proposed the usage of Hammerstein-Wiener (H-W) method for the modelling purpose. Experiment is set up to obtain the naturalistic data for the modelling process. The modelling process is carried out by varying the input output nonlinearities estimators. The results show that the estimated output responses from the H-W models are similar with the real responses taken from the experiment.The derived models for both passenger and driver have 68.88% and 66.32% of Best Fit (BF) percentages. With further study, the passenger's and driver's models which are developed by the proposed H-W modelling strategy are expected to contribute in MS minimisation studies.

Index Terms*: Hammerstein-Wiener, Head tilt movement, Lateral Acceleration, Motion sickness, Modelling.

I. INTRODUCTION

Motion Sickness (MS) is an uncomfortable condition includes headache, nausea, drowsiness, vomiting and other physical discomfort which happenedwhile travelling [1], [2]. It is well known that the passengers experienced more MS compared to the drivers [3]. This is due to the different head tilt movement by the passengers and the drivers with respect to the vehicle's lateral acceleration direction during cornering [4]. As shown in Fig. 1, normally, when negotiating to a curve, the direction of the head tilt movement by the passenger is same with the direction of the lateral acceleration.Meanwhile, the direction of the head tilt movement by the driver is against the direction of the lateral acceleration. The degree of the head movement is quantified by measuring the occupant's head roll angle.

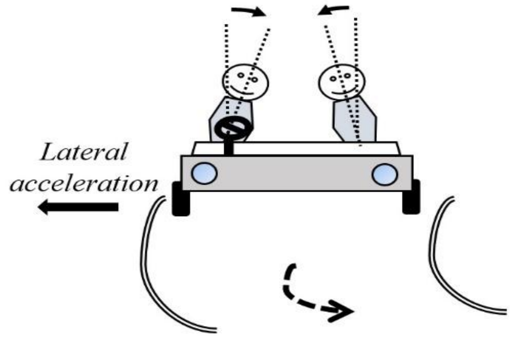

Fig. 1 - Typical occupant's head tilt movement during cornering

There are MS mitigation studies which implemented the occupant's head movements strategy by placing a postural device onthe passenger front seat to minimise the head roll angle towards the direction of the lateral acceleration [5], [6]. In our opinion, various kinds of strategies can be designed to reduce MS by using the same strategy. However, the implementation will be convenient if the relation of the occupant's head roll and vehicle's lateral acceleration is expressed mathematically. Previously, their relationship has been modeled by using Linear Transfer Function [7] and Artificial Neural Network (ANN) [8] methods.

Alternatively, this study proposed to model the relationship between the occupant's head roll and lateral acceleration via Hammerstein-Wiener (H-W) modelling method. H-W is one of the nonlinear system models [9]. It is widely used in nonlinear System Identification (SI) field [10]. It is also being applied in modelling and control design in control engineering field [11]. The advantages of using a block-oriented nonlinear model like H-W are it is simple to understand and easy to use [12]. Thus, it is suitable to apply H-W method to model the head tilt movement behaviour which is nonlinear in nature. For the modelling purposes, an experiment with real scenario that provoked MS is set up to collect the naturalistic data. There are several input and output nonlinearity estimator that can be selected during

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Sarah 'AtifahSaruchi*, Malaysia-Japan International Institute of Technology (MJIIT), UniversitiTeknologi Malaysia (UTM), 54100 Kuala Lumpur, Malaysia.

Mohd Hatta Mohammed Ariff*, Malaysia-Japan International Institute of Technology (MJIIT), UniversitiTeknologi Malaysia (UTM), 54100 Kuala Lumpur, Malaysia.

HairiZamzuri, Malaysia-Japan International Institute of Technology (MJIIT), UniversitiTeknologi Malaysia (UTM), 54100 Kuala Lumpur, Malaysia.

Nurhaffizah Hassan, Faculty of Electrical Engineering, UniversitiTeknologi Mara (UiTM), 23000 Dungun, Malaysia.

Nurbaiti Wahid, Faculty of Electrical Engineering, UniversitiTeknologi Mara (UiTM), 23000 Dungun, Malaysia.

Noor Jannah Zakaria, Malaysia-Japan International Institute of Technology (MJIIT), UniversitiTeknologi Malaysia (UTM), 54100 Kuala Lumpur, Malaysia.

the modelling process. In this study, trial and error strategy is used to find the suitable estimators which can constructed the best performance model.

II. METHODOLOGY

The research works starts by carried out an experiment for data collection. It is necessary to have the data because it will be used during the modelling process. The second phase of this study is the modelling stage by the H-W method. In this phase, different sets of input and output nonlinearity estimators are used to acquire the best correlation model. Lastly, all the developed models are analysed in terms of its Best Fit (BF) percentages and errors.

A. The Experimental Setup

For the modelling purpose, an experiment is conducted to collect the naturalistic data of the head roll angle and lateral acceleration. The experiment is inspired by Wada etal [13]. Fig. 2 shows the illustration of the slalom course which is designed to obtain low frequency of lateral acceleration to create situation that provoked MS. Six cones are used to form a 150 m straight line. The gap for every cone is 20 m. The drivers are instructed to perform a slalom drive through the cones. The velocity is set to be constant at 30 km/h.

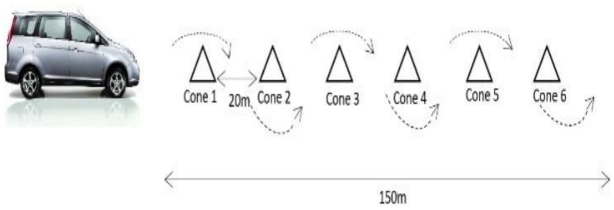


Fig. 2 - Schematic of the test track

The experiment is participated by 10 healthy adults regardless of their ages, genders and driving skills. Each participant participated as both passenger and driver in randomized order. They took part as passenger and driver for three times per role.

Before started, all the participants are required to go through trial sessions. This is to ensure that they get accustomed to the slalom driving. The trial sessions also reduced the possibility of moving their heads unnaturally during the test. Three sensors are used to measure the lateral acceleration and head roll angle. Two of them are attached at the participant's caps, and one of them is being placed at the flat space near the hand brake. The sensors are then connected to Dewesoft, a device which is used as the data acquisition module. Fig.3 shows the illustration of the motion sensor placement which is placed on the participant's cap.

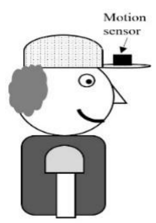
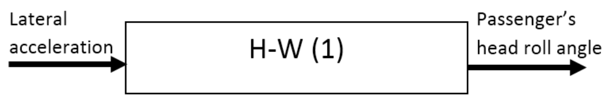


Fig.3 – Sensors attached on the participant's caps.

B. Hammerstein-Wiener Modelling

The models to represent the relationship between vehicle lateral acceleration and head roll for the passenger and the driver are derived separately. For the passenger's model, the input for the system is lateral acceleration and passenger's head roll angle. On the other hand, the input and output for the driver's model are lateral acceleration and driver's head roll angle. Fig. 4 presents the architecture of both passenger's and driver's models.



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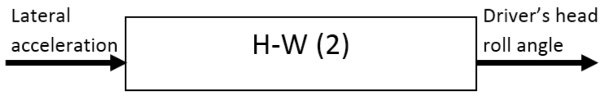


(b)

Fig. 4 - Architecture of the relationship models for (a) passenger and (b) driver

H-W model is a model where a nonlinear block precedes and follows a linear dynamic system [14]. Fig. 5 illustrates the general overview of the structure of H-W that being used in this study [15]. It consists of a linear dynamic with two nonlinear steady-state blocks [16].

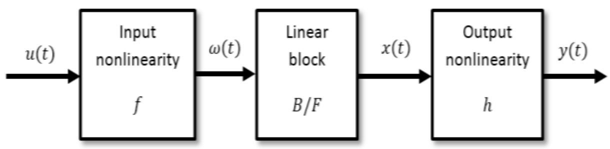


Fig. 5 - Structure of H-W model

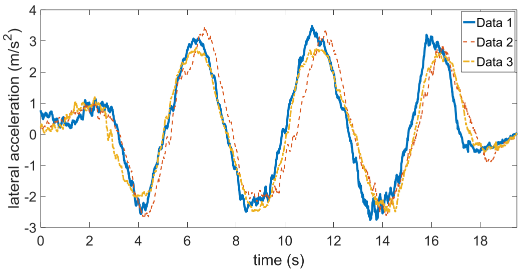
Based on Fig. 5, $u(t)$ is input data, $y(t)$ is output data, $\omega(t) = f(u(t))$ is nonlinear function converting input data, $x(t) = B/F(\omega(t))$ is linear function while f and h are nonlinear functions.

In this study, the selection of nonlinearity estimators in the modelling process is determined by trial and error method. The estimators that being tested includes Linear Function, Sigmoid Network Function, Wavelet Network Function and Polynomial [17]. The combination of nonlinearity estimators which produced models with the highest Best Fit (BF) percentages is selected and considered to be the best.

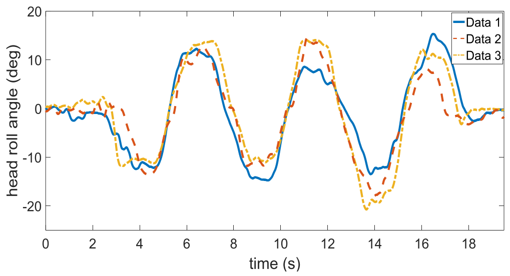
III. RESULTS AND DISCUSSION

A. Experimental Results

Fig. 6(a), 6(b) and 6(c) illustrates the real responses of the vehicle lateral acceleration, head roll angle of the passenger and head roll angle of the driver which are taken from three driving data. According to the figures, the direction of the head roll angle of the passenger is synchronized with the direction of the lateral acceleration. Besides, the direction of the head roll angle of the driver is opposite to the direction of the lateral acceleration. The responses matched well with the typical occupant's head tilt movements in Fig. 1. These data are then used in the modelling stage. A data from the passenger's and driver's data collection are extracted respectively and being excluded during the modelling process. These data are called as unseen data.



(a)



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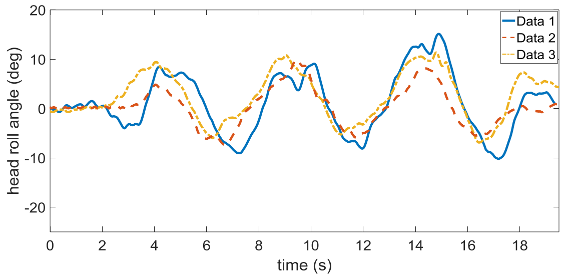

(c)

Fig. 6 Examples of (a) vehicle's lateral acceleration; (b) passenger's head roll; and (c) driver's head roll from three driving data

B. Modeling Results and Analysis

N The H-W modelling process is conducted by using the MATLAB software. During the process, several input and output nonlinearity estimators are used. Table 1 tabulates the H-W modelling results consists of Best Fit (BF), Final Prediction Error (FPE) and Mean Squared Error (MSE).

In this study, the best model is determined by choosing the highest BF percentages. Based on Table 1, the best passenger's model is generated by the combination of wavelet and polynomial estimators with 68.88% of BF percentage. On the other hand, the application of polynomial as both input and output estimators managed to produce the best driver's model with 66.32% of BF percentage.

The effectiveness of the best passenger's and driver's models are analysed by comparing their estimated output responses with the unseen data that is taken from the experiment. Fig. 7 shows the comparison results between the estimated and unseen data responses. Based on the results, the models able to produce similar estimated output responses with the unseen data responses. For the detail analysis, the comparison error is calculated from both responses. Table 2 tabulates the comparison error in Root-Mean-Squared (RMS) values.

Table 1. H-W modelling results with different input-output nonlinearity estimators

Input Estimator	**Output Estimator**	**BF (%)**		**FPE**		**MSE**	
		Passenger	**Driver**	**Passenger**	**Driver**	**Passenger**	**Driver**
Linear	Linear	65.31	64.23	12.06	4.283	11.99	4.260
	Sigmoid	63.71	63.96	13.53	4.387	13.44	4.358
	Wavelet	50.62	18.58	17.93	21.85	17.77	21.66
	Polynomial	65.88	64.73	11.91	4.266	11.87	4.252
Sigmoid	Linear	64.94	64.51	13.20	4.408	13.12	4.380
	Sigmoid	61.62	64.01	14.83	4.398	14.72	4.365
	Wavelet	63.95	26.16	13.65	18.60	13.52	18.41
	Polynomial	66.15	65.31	12.44	4.312	12.39	4.293
Wavelet	Linear	61.79	64.68	11.83	4.346	11.79	4.328
	Sigmoid	65.58	65.21	12.36	4.351	12.30	4.329
	Wavelet	64.39	64.80	12.17	4.300	12.09	4.263
	Polynomial	**68.88**	64.88	12.62	4.366	12.60	4.357
Polynomial	Linear	64.65	64.48	11.90	4.271	11.86	4.258
	Sigmoid	65.57	65.11	12.35	4.354	12.30	4.335
	Wavelet	64.37	64.86	12.17	4.302	12.09	4.274
	Polynomial	65.76	**66.32**	12.42	4.442	12.41	4.437

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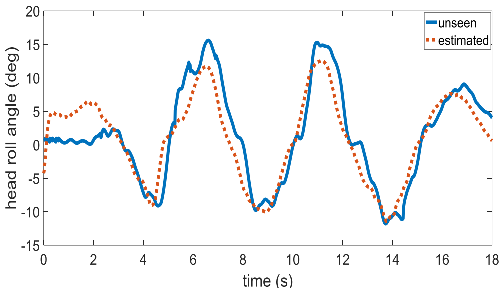

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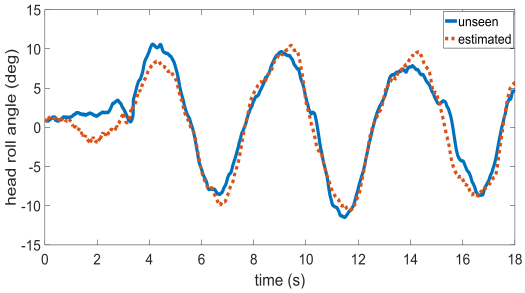

(b)

Fig. 7 - Comparison results between unseen and estimated responses for (a) passenger's and (b) driver's models

Table 2. Comparison error between unseen and estimated responses

Error	Passenger	Driver
Comparison Error (RMS)	3.6618	3.4470

IV. CONCLUSION AND FUTURE WORK

It has been proven by the previous studies that the occupant's head tilt movement is correlated with the vehicle's lateral acceleration during the curve driving. It is believed that the correlation is significant and can be useful in MS mitigation studies if their relationship can be expressed mathematically. Therefore, this study proposed the application of H-W modelling method to model the relationship. According to the modelling results, the developed passenger's and driver's models able to generate similar output responses with the unseen data.It is an indicator that the proposed modelling strategy is succeeded in developing the correlation models. In our view, these models constitute a great potential in MS minimisation study. However, for the future works, it is encouraged to improve the modelling to get better performance.

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REFERENCES

1. C. T. Lin, S. F. Tsai, H. C. Lee, H. L. Huang, S. Y. Ho, and L. W. Ko,"Motion sickness estimation system," Proc. Int. Jt. Conf. Neural Networks, pp. 10–15, 2012.
2. C. Diels and J. E. Bos, "User interface considerations to prevent self-driving carsickness," Adjun. Proc. 7th Int. Conf. Automot. User Interfaces Interact. Veh. Appl. - AutomotiveUI '15, pp. 14–19, 2015.
3. T. Wada, "Motion Sickness in Automated Vehicles : The Elephant in the Room Motion sickness," Int. Symp. Adv. Veh. Control, no. September, pp. 121–129, 2016.
4. T. Wada, H. Konno, S. Fujisawa, and S. S. Doi, "Can Passengers' Active Head Tilt Decrease the Severity of Carsickness?: Effect of Head Tilt on Severity of Motion Sickness in a Lateral Acceleration Environment," Hum. Factors J. Hum. Factors Ergon. Soc., vol. 54, no. 2, pp. 226–234, 2012.
5. H. Konno, S. Fujisawa, T. Wada, and S. Doi, "Analysis of Motion Sensation of Car Drivers and Its Application to Posture Control Device," SICE Annu. Conf., pp. 192–197, 2011.
6. S. Fujisawa, T. Wada, H. Konno, and S. Doi, "Analysis of Head-tilt Strategy of Car Drivers and Its Application to Passenger ' s Posture Control Device," SICE J. Control. Meas. Syst. Integr., vol. 48, no. 1, pp. 60–66, 2012.
7. S. 'A. Saruchi,H.Zamzuri, N. Hassan, M.H. M. Ariff, " Modeling of Head Movements towards Lateral Acceleration Direction via System Identification for Motion Sickness Study," Int. Conf. Inf. Commun. Technol. pp. 633–638, 2018.
8. S. 'A. Saruchi, M. H. M.Ariff, H. Zamzuri, N. Hassan and N. Wahid, "Artificial neural network for modelling of the correlation between lateral acceleration and head movement in a motion sickness study," IET Intelligent Transport Systems, vol. 13, no. 2, pp. 340-346, 2019.
9. X. S. Luo and Y. D. Song, "Data-driven predictive control of Hammerstein–Wiener systems based on subspace identification," Inf. Sci. (Ny)., vol. 422, pp. 447–461, 2018.
10. J. Yan, B. Li, H. Ling, H. Chen, and M. Zhang, "Nonlinear State Space Modeling and System Identification for Electrohydraulic Control," vol. 2013, 2013.
11. C. Karthik, A. Ramalakshmi, and K. Valarmathi, "Support Vector Regression For Hammerstein-Wiener Model Identification," 2016 Int. Conf. Comput. Technol. Intell. Data Eng., pp. 1–5, 2016.
12. M. Schoukens, A. Marconato, R. Pintelon, G. Vandersteen, and Y. Rolain, "Parametric identification of parallel Wiener-Hammerstein systems," Automatica, vol. 51, pp. 111–122, 2015.
13. T. Wada, S. Fujisawa, and S. Doi, "Analysis of Driver's Head Tilt Using a Mathematical Model of Motion Sickness," Int. J. Ind. Ergon., pp. 1–9, 2016.
14. A. Wills, T. B. Schön, L. Ljung, and B. Ninness, "Identification of Hammerstein-Wiener models," Automatica, vol. 49, no. 1, pp. 70–81, 2013.
15. M. S. Gaya et al., "Estimation of turbidity in water treatment plant using hammerstein-wiener and neural network technique," Indones. J. Electr. Eng. Comput. Sci., vol. 5, no. 3, pp. 666–672, 2017.
16. M. Ławryńczuk, "Nonlinear predictive control for Hammerstein-Wiener systems," ISA Trans., vol. 55, pp. 49–62, 2015.
17. A. Alqahtani, M. Alsaffar, M. El-sayed, and B. Alajmi, "Data-Driven Photovoltaic System Modeling Based on Nonlinear System Identification," Int. J. Photoenergy, vol. 2016, pp. 1–9, 2016.

AUTHORS PROFILE

Sarah 'Atifah. Saruchi received her BEng in Mechanical and Aerospace engineering from Nagoya University, Japan. She then received her MPhil from the Malaysia-Japan International Institute of Technology, UniversitiTeknologi Malaysia. Currently, she is pursuing her Ph.D. under the same institution. Her research interests include vehicle control systems and Artificial Intelligence (Ai).

Mohd Hatta MohammedAriff received his BEng. in Electronic and Electrical Engineering from the University of Liverpool, UK. Then, he received his MSc. in High Voltage Engineering from Universiti Putra Malaysia. He obtained his Ph.D. from UniversitiTeknologi Malaysia. Currently, he is

working as alecturer in UniversitiTeknologi Malaysia. His research interests mainly focus on advanced vehicle dynamic system, control system and machine learning.

HairiZamzuri received his BEng in Control Systems and his Master of Electrical Engineering from UniversitiTeknologi Malaysia. He then received his Ph.D. in Artificial Intelligence (Ai) and control design from Loughborough University, UK. Currently, he is an Associate Professor in UniversitiTeknologi Malaysia. His research interests are vehicle dynamic control and robotics.

Nurhafizzah Hassan received her BEng Electrical from UniversitiTeknologi Mara, Malaysia. Then she received her MEng in Mechatronic and Automatic Control from UniversitiTeknologi Malaysia. Currently, she is pursuing her Ph.D. in the machine learning field at the same university. Her research interests areArtificial Intelligence (Ai) and control system.

Nurbaiti Wahid received her BEng Electrical, MEng and Ph.D from UniversitiTeknologi Malaysia. Currently, she is senior lecturer in UniversitiTeknologi Mara, Malaysia. Her research interests mainly aboutcontrol system, vehicle dynamic and motion planning.

Noor Jannah Zakaria received the B. E. degree in Electronic System Engineering from the Malaysia-Japan International Institute of Technology, UniversitiTeknologi Malaysia, Kuala Lumpur, Malaysia, in 2017.She is currently pursuing the master's degree with the Malaysia-Japan International Institute of Technology, UniversitiTeknologi Malaysia. Her research interests are Artificial Intelligence (Ai) and Object Detection.