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Quantifying the automated vehicle passenger's level of comfort in the longitudinal and lateral direction

Juffrizal Karjanto[1,2,3,*], Hielke Wils[3], Nidzamuddin Md. Yusof[1,2,3], Mohamed Ihsan Sabri Mohamed Nazar[4], Jacques Terken[3], Frank Delbressine[3], Matthias Rauterberg[3]

[1)] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[3)] Department of Industrial Design, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, Netherlands.
[4)] Fakulti Teknologi Kejuruteraan, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh , Panchor, 84600, Johor, Malaysia.

[*]Corresponding e-mail: juffrizal@utem.edu.my

Keywords: Automated driving; comfort perception; lateral and longitudinal acceleration

ABSTRACT – Automating the driving task is a relatively new topic in the automotive industry. Hence, this study aimed to investigate the perception of the comfort of passengers in an automated vehicle (AV) and to establish physical boundaries for what they perceive as comfortable. Acceleration data and discomfort rating were collected and analysed. It was found that longitudinal accelerations below 0.57 m/s² (r.m.s.) and lateral accelerations up to 0.70 m/s² (r.m.s.) is perceived as comfortable.

1. INTRODUCTION

While the fully automated vehicle (AV) has been the future of the automotive industry, there is uncertainty regarding how the vehicle will be operating on the road. Since a human user is no handling the driving task, determining the user's perception in terms of how the AV is driving is crucial in accelerating the adoption rate of this technology. More specifically, a need for explicit quantification of passenger's perception in terms of AV's driving style (DS) on the road so that the user's riding experience can be improved.

In general, it is known that preferences for vehicle comfort settings may vary depending on different factors; one of them is the person's DS [1]. Since AVs are categorised as robots, they are supposed to behave according to the most efficient, optimal and safest way of operation. However, for AV users to feel comfortable inside the vehicle, the users' preferences have to be matched with the AV's DS [2]. Regardless of their DS, drivers mentioned that they would prefer all exerted forces to be in the range of a defensive DS. To enhance perceived comfort, AV driving would not necessarily have to be less dynamic than manual driving [3]. Other findings suggested that rather aggressive DS, involving frequent acceleration and braking, probably cause motion sickness (e.g., [4]). This study aims to quantify the physical boundaries for what AV passengers perceive as comfortable.

2. METHODOLOGY

Fourteen people (10 males and 4 females aged between 19 and 31 years old (Mean = 23.5, SD = 3.8) participated in this study. The participants were driven in a backseat of an instrumented vehicle which was built to mimic an AV in terms of driving and appearance (see [5] for further explanation on the test setup). All of the AV's test rides were done within the Eindhoven University of Technology's compound where Dutch traffic laws and regulations apply.

The study consisted of two experiment sessions with two DS which are characterised by typical ranges of acceleration, as shown in Table 1, and have been validated in previous studies on AV riding experience [6]. Accelerations data were collected from the accelerometer sensors placed close within the test vehicle's centre of gravity. A 5-point Likert unipolar self-rating scale was used as comfort perception since it was aimed at investigating varying levels of the same concept (i.e., feeling of discomfort).

Table 1 Ranges of acceleration for AV driving style (DS) in tri-axial directions, 1.00 g = 9.81 (m/s²).

Acceleration	Defensive AV DS	Assertive AV DS
Longitudinal acceleration	0.14 g to 0.25 g	0.25 g to 0.50 g
Longitudinal deceleration	- 0.14 g to - 0.33 g	- 0.33 g to - 0.76 g
Lateral acceleration	0.15 g to 0.42 g	0.42 g to 0.54 g

3. RESULTS AND DISCUSSION

A linear regression established that discomfort rating during driving could statistically significantly predict longitudinal acceleration/deceleration, a_x (r.m.s.), $F(1,26) = 11.41$, $p = 0.002$ and discomfort during driving accounted for 30.5% of the explained variability in a_x (r.m.s.), with adjusted $R^2 = 0.28$. The regression equation was: a_x (r.m.s.) = 0.35 + 0.11*(discomfort rating during driving) and is shown in Figure 1. A Pearson's product-moment correlation indicated statistically significant ($p < 0.01$) between the level of comfort and a_x (r.m.s.).

Predictions were made to determine a_x (r.m.s.) for discomfort ratings of 1 (not uncomfortable at all), 2 (slightly uncomfortable), and 3 (moderately uncomfortable). For rating equal to 1, a_x (r.m.s.) was predicted as 0.46 (m/s²), 95% CI [0.36, 0.56]; for rating equal to 2, a_x (r.m.s.) was predicted as 0.57 (m/s²), 95% CI [0.51, 0.64]; and for rating equal to 3, a_x (r.m.s.) was predicted as 0.69 (m/s²), 95% CI [0.59, 0.78]. The level slightly uncomfortable was assumed to be the upper boundary of what is tolerable, in terms of discomfort. Therefore, 0.57 (m/s²) was considered as an upper boundary for longitudinal r.m.s. acceleration that is perceived as comfortable.

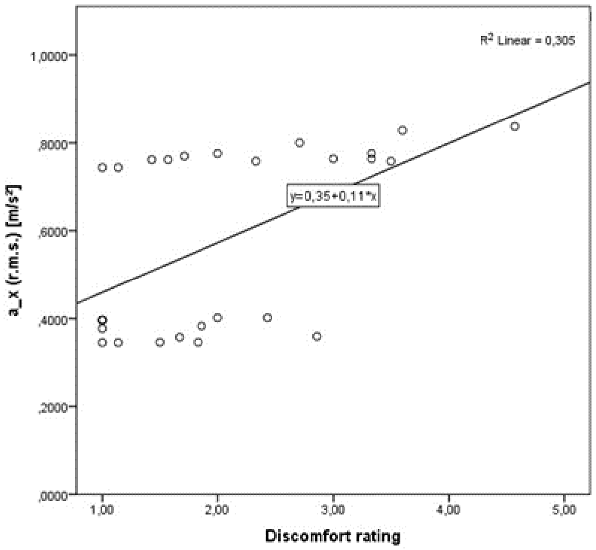

Figure 1 Linear regression of rating and frequency-weighted r.m.s. acceleration in the longitudinal direction

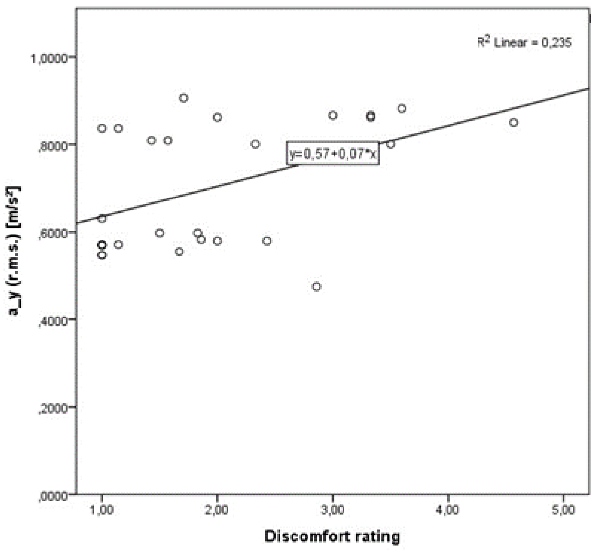

Figure 2 Linear regression of rating and frequency-weighted r.m.s. acceleration in lateral direction

A linear regression established that discomfort rating during driving could statistically significantly predict lateral acceleration, a_y (r.m.s.), F (1,26) = 8.01, p = 0.009 and discomfort during driving accounted for 23.50% of the explained variability in a_y (r.m.s.), with adjusted $R^2 = 0.21$. The regression equation was: a_y (r.m.s.) = 0.57 + 0.069*(discomfort rating during driving) and is shown in Figure 2. Pearson's product-moment correlation indicated statistically significant ($p < 0.01$) between the level of comfort and a_y (r.m.s.).

Predictions were made to determine a_y (r.m.s.) for discomfort ratings of 1 (not uncomfortable at all), 2 (slightly uncomfortable), and 3 (moderately uncomfortable). For rating equal to 1, a_y (r.m.s.) was predicted as 0.64 (m/s²), 95% CI [0.56, 0.71]; for rating equal to 2, a_y (r.m.s.) was predicted as 0.70 (m/s²), 95% CI [0.66, 0.75]; and for rating equal to 3, a_y (r.m.s.) was predicted as 0.77 (m/s²), 95% CI [0.70, 0.84]. The level *slightly uncomfortable* was assumed to be the upper boundary of what is tolerable, in terms of discomfort. Therefore, 0.70 (m/s²) was considered as an upper boundary for tolerable lateral r.m.s. acceleration, in terms of subjective comfort.

4. CONCLUSION

It was found that longitudinal accelerations below 0.57 m/s² (r.m.s.) and lateral accelerations up to 0.70 m/s² (r.m.s.) is perceived as comfortable in AV driving.

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Editorial Preface

This open access e-proceedings contains a compilation of 170 selected papers from the 7th Mechanical Engineering Research Day (MERD'20) that was held virtually at Kampus Teknologi UTeM, Melaka, Malaysia, on 16 December 2020. The event was jointly organized by the Faculty of Mechanical Engineering and Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka. This year, MERD is also be co-organized by Graduate School of Engineering, Nagoya University, Japan.

It was gratifying to all of us when the response for MERD'20 is overwhelming as the technical committees received 230 submissions from various areas of mechanical engineering and related fields to facilitate the mutual understanding of fundamentals, theory and applications including Automotive, Additive Manufacturing, Advanced Materials and Processes, Computer Modeling and Simulation, CBM, Mechanical Vibration and Control, Energy Engineering and Management, Engineering Education, Mechanical Design and Optimization, Structural and Mechanical Testing, Surface Engineering and Tribology, Thermal and Fluids. All submitted papers are then peer-reviewed, revised according to the reviewers' comments and ultimately 170 papers were accepted for publication in this proceeding. This open access e-proceedings can be viewed or downloaded via www3.utem.edu.my/care/proceedings. We hope that this proceeding will serve as a valuable reference for researchers.

With the large number of submissions, the event has achieved its main objective which is to bring together educators, researchers, and practitioners to share their findings and perhaps sustaining the research culture in the university and industry.

As the editors-in-chief, we would like to express our gratitude to the fellow review members for their tireless effort in reviewing the submitted papers for this proceeding. We also would like to say special thanks to all the authors for promptly revising their papers according to the proceeding requirements. Special thanks are extended to the organizer of the MERD'20.

Thank you

Mohd Fadzli Bin Abdollah
Hilmi Amiruddin
Amrik Singh Phuman Singh
Editors-in-Chief
Universiti Teknikal Malaysia Melaka

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