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Objective Assessment of Cybersickness in a Stationary Helicopter Simulator Using Pupil Diameter as a Quantitative Indicator

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Abstract—**Motion sickness (MS), particularly the type triggered by visual cues known as visually induced motion sickness (VIMS), occurs due to conflicting sensory signals and can arise from various visual devices like video games, VR, and simulators. Termed cybersickness in virtual environments, it can negatively impact health, simulator effectiveness, and VR training outcomes. Detecting and quantifying MS is essential for developing countermeasures. Existing research on cybersickness, particularly its relationship with physiological responses like pupil diameter (PD), has yielded inconsistent findings. This study focuses on cybersickness in a stationary helicopter simulator, using PD as a measure. It investigates how different weather conditions (clear vs. stormy) affect cybersickness, measured by the simulator sickness questionnaire (SSQ), and examines the correlation between SSQ scores and PD changes. The findings show a significant increase in SSQ total score from clear to stormy weather conditions. The results also suggest a trend of increased pupil diameter over time in stormy conditions with a slight significance.**

I. Introduction

In 1881, Irwin [1] used the term "motion sickness (MS)" to explain the occurrence of seasickness. Irwin explained that seasickness is not only induced by turbulent water, but also by various other motions in different directions for an appreciable time. MS [1, 2] is a common phenomenon that appears to have started ever since humankind started travelling [3]. MS is a typical disruption that appears in healthy individuals as a physiological reaction due to unpredictable movements based on prior experience or conflict between the perceived sensation from different sensory systems [4, 5]. Transportation, automobile and entertainment industries have broadened the spectrum of provocative movement experiences over the past centuries to vehicles, tilting planes, funfair rides, planes, space, virtual reality (VR), and simulators [6, 7] Most people have experienced those unpleasant feelings of dizziness, nausea, vomiting, drowsiness, stomach awareness and discomfort, which are the main symptoms of MS, during travels at least once in a [4], 8, 9]

According to the sensory conflict theory, MS is the result of a disparity between the information provided by sensory systems like the visual, vestibular, and proprioceptive systems, and the perceived information. That is, if the incoming signals are different from the stored information in the central nervous system (CNS), then the sensory conflict occurs leading to MS [10 – 13]. The theory of eye movement explains that moving visual cues can trigger the vagal nerve leading to MS symptoms. Although these theories provide an explanation to what might be the cause behind MS, the issue of MS remains to be unsolved yet MS [13].

While VR technology has been significantly improved and successfully used in different domains, it still has not achieved its expected growth as a consumer-grade technology. The advent of HMDs has introduced another form of sickness known as "cybersickness" due to associated functional issues such as latency between actual head motions and the produced picture, which can cause unpleasant symptoms. Nowadays, simulator sickness and cybersickness are used interchangeably to describe motion sickness induced by VR [14]. Motion simulators serve as invaluable tools in training and human performance analysis, providing researchers and instructors with valuable insights into human behaviour, decision-making, and skill acquisition in both simulated driving and aviation environments [15 – 21]. Motion simulators equipped with high-efficiency motion cueing algorithms can provide a realistic environment for training and human performance analysis [18 – 23].

The type of MS which is mainly triggered by visual cues rather than by physical motion cues is referred to as visually induced motion sickness (VIMS). In general, VIMS can take many forms depending on each specific types of visua devices such as video gaming sickness, cinerama sickness, VR sickness, cybersickness, or simulator sickness. Although the implementation of simulators and VR might also include using moving platforms and the provoked symptoms are not purely attributed to visual inputs, this still falls under VIMS since the main factor of experiencing motion sickness can be the visual system [24, 25]. The correlation between the actual motion and how it causes MS has been widely investigated and prediction approaches have been developed (e.g. [26]); however, how MS is visually induced by only visual cues is still unclear [24]. Physiological data are widely used as effective measures for analysing human performance (e.g., motion sickness, stress, cognitive load, human behaviour, and etc.) [27 - 29].

One of the essential keys of exposure to VR/Virtual Environment (VE) based simulators is the user comfort during simulated scenarios [30]. Adverse results, such as discomfort, can make training sessions shorter and increase dropout rates of users [30 – 32]. Several studies [33 – 35] reported a high

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dropout rate of participants due to experiencing adverse effects such as nausea. Furthermore, adverse effects can become extreme and might require immediate attention at the hospital [35, 36].

Recent investigations into the physiological effects of virtual reality (VR) have examined how pupil dynamics correlate with cybersickness. Chen et al. [37] demonstrated that both negative and positive emotive VR content can lead to pupil dilation, with haptic-visual feedback causing the most significant change in pupil size. This finding suggests that multi-sensory feedback in VR can significantly influence pupil response [37]. This is in line with previous research that showed pupil dilation can be a response to emotional arousal, with dilation occurring in response to pleasant images and constriction in response to unpleasant ones (Hess et al., 1960 as cited by Chen et al. [37]).

Another research by Ozkan and Celikcan [27] has shown that pupil diameter tends to decrease in response to VR-induced cybersickness, particularly when the VR experience requires focusing on nearby objects, triggering what is known as the "pupil near response". Yet, increased pupil size has also been associated with cybersickness, especially when related to movement speed within the VR environment.

It was further observed by Ozkan and Celikcan [38] that eye-activity features, such as changes in pupil size, vary in response to different types of VR-induced cybersickness across various sessions. The progression of VR sessions has been linked with an increase in symptoms like nausea, oculomotor discomfort, and disorientation, indicating that the severity of persistent cybersickness may change with each session.

Together, these studies suggest a complex relationship between pupil size changes and cybersickness, influenced by several factors, including the type of VR content, the presence of emotional triggers, and the duration of VR exposure. The findings highlight the need for ongoing research to fully understand the physiological responses to VR and how to optimize VR experiences for user comfort[37, 38].

Limited number of studies reported that cybersickness contributed to significant changes in human biophysiological signals, such as PD reduction in VR [39] and stereoscopic video movies [40] Koo et al. [41] studied the changes in PDs in relation to subjective scores of visual fatigues. The study concluded that visual fatigue increased while watching videos, especially in younger participants. The increase in fatigue was accompanied by a decrease in PD in most of the viewing period. On the other hand, a study by Park et al. [42] concluded that an increase in PD was reported during motion sickness.

There is still ongoing research on finding correlations between cybersickness and the change of PD; however, (i) no consistent findings were found, (ii) the control of simulated vehicles was limited to artificial intelligence (AI), therefore, there is a need to assess cybersickness while human in control of the simulated vehicle (iii) also, the test scenarios in the simulated environment are limited to one default scenario at optimal weather conditions. Therefore, the motivation of this study was to further investigate PD as a reliable and consistent indicator of MS.

This study explored the impact of weather conditions, including clear and stormy, on cybersickness levels in a virtual reality helicopter simulator. Objective measures, such as changes in PD, were used to assess cybersickness. Additionally, participants completed the Simulator Sickness Questionnaire (SSQ) for subjective scoring.

This conducted research aimed to investigate how the change in weather conditions (such as weather change from clear to stormy) affects MS level and PD size. In addition, the overall correlation between MS and PD. We hypothesised that MS level increases when the weather changes from clear to stormy. We also hypothesised that there is a significant correlation between the change in MS level and the change in PD size when considering different weather conditions.

II. Research Materials and Methods

A. Participants

Sixteen males aged 18 to 45 volunteered for this study. All data collection and experiments adhered to COVID-19 regulations and guidelines, and the research was approved by the Ethic Committee of Deakin University. All participants completed a COVID-19 screening form, read and signed the consent form, and were provided with a plain language statement (PLS).

All participants were asked to complete a pre-SSQ to assess their wellbeing before conducting the experiment. Participants underwent a 10-minutes training session (5-min flatscreen training and 5-min HMD training). The main objective of the training session was to equip participants with basic knowledge and experience in flying and operating the helicopter simulator.

The flying scenario consisted of 4 different weather conditions namely: “clear”, “broken” and “stormy” weather and “controlled by artificial intelligence”. The duration of each scenario was up to 7-min. However, only the results from two scenarios, clear and stormy weather conditions, were used in this article.

B. Procedure and Experimental Setup

The experiment comprised of three key phases. Initially, participants received a briefing on the experiment's objective, followed by the attachment of measurement devices to their bodies after completing relevant forms. Then participants answered a pre-SSQ, followed by a 10-minute helicopter training session. Those with a history of severe MS, as indicated by their pre-SSQ answers, were excluded from the experiment.

Random order of flying scenarios was assigned to participants. Participants were tasked to fly figure-8 like pattern. Participant were asked to complete a post-SSQ at the end of each scenario. This study adopted a 0-10 scale to complete both SSQs (pre- and post-SSQs), rather than using the 0-3 scale SSQ by Kennedy et al. [43] so that the scale provided has more flexibility

C. Helicopter Simulator and Devices

In this work, the flight simulation was carried out using Xplane11, focusing on the Sikorsky S-76 helicopter, which cruises at 155 knots. The objective was to explore the effects of distinct weather conditions on cybersickness and

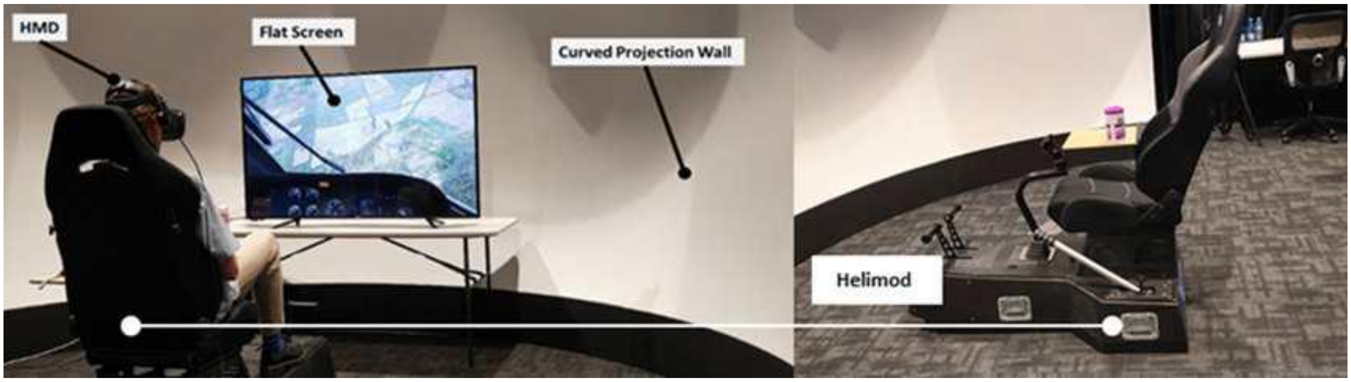

Fig. 1. Experimental setup: Display (left) and stationary platform Helimod (right).

Fig. 2. Screenshots from Xplane 11's environment. Clear weather (left) and stormy weather (right)..

physiological responses. Two weather scenarios were examined: the default 'clear' setting in Xplane11 and a 'stormy' environment that was tailored with a specific configuration. This configuration included a cloud layer and two wind layers: the first wind layer had a direction of 52 degrees with gusts reaching 16 knots at an altitude of 25,000 feet (mean sea level, msl), and the second was directed at 70 degrees with a steady wind of 14 knots and similar gusts at 2,500 feet (msl). Comparative visuals of these weather conditions are presented in Figure 2.

The experimental flights within the study utilized the Avalon airport in Victoria, Australia as a standard take-off and landing site across all scenarios, chosen for its familiarity to the participants. Pilots were instructed to follow a number-8-like flight pattern, a route that incorporates both linear trajectories and acute manoeuvres.

The research employed a stationary helicopter simulator connected to a desktop computer with robust specifications: a 64-bit Windows 10 operating system, an Intel Core i7-9700 CPU clocked at 3.60GHz, a Z390 X-CF motherboard, 32GB of RAM, and an NVIDIA GeForce RTX 2080 Super with 8GB of video memory. Data capture was achieved using an HTC Vive Head-Mounted Display (HMD), integrated with Tobii Pro VR technology. This setup enabled the collection of detailed eye-tracking data, including pupil size for each eye.

III. RESULTS AND DISCUSSION

In the group of participants, 56% wore corrective eyewear, and 69% had previously experienced motion sickness (MS). Notably, there were no reports of pre-existing discomfort before the experiments commenced. All the participants successfully completed a 7-minute flight under clear weather conditions in the simulator. Nevertheless, during the stormy weather simulation, two participants reported intense cybersickness and requested to end their flight sessions early.

The Total Score (TS) for cybersickness in the study was determined using the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. [32]. The calculation of the SSQ score included an analysis of the key decision making factors in sixteen questions, determined by three groups of symptoms: nausea (N), oculomotor (O) and disorientation (D). The calculation of the TS score is calculated using the following equations:

$$N = 9.57 \times (a) \quad (1)$$

$$O = 7.58 \times (b) \quad (2)$$

$$D = 13.92 \times (c) \quad (3)$$

$$MS\ Total\ Score(TS) = ((a) + (b) + (c)) \times 3.74 \quad (4)$$

where (a) = Σ (General discomfort, Difficulty focusing, Increased salivation, Sweating, Nausea, Stomach awareness, Burping), (b) = Σ (General discomfort, Fatigue, Headache, Eyestrain, Difficulty focusing, Difficulty concentrating, Blurred vision), and (c) = Σ (Difficulty focusing, Nausea, Fullness of head, Blurred vision, Dizziness eyes open, Dizziness eyes closed, Vertigo) [32]. The scores for each group range from 0-200 for N, 0-292 for D, 0-159 for O and 0-179 for TS [14].

Figure 3 The graph presents a regression analysis using data from the Simulator Sickness Questionnaire (SSQ) to compare Total Sickness (TS) scores across different simulated weather conditions. Individual participant scores are denoted by blue points, illustrating the variation in reported sickness. The red regression line, marked with an Rsquared value of 0.84, signifies a robust positive correlation, indicating that

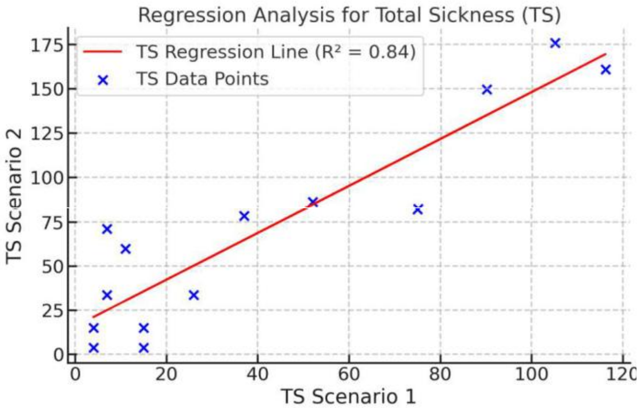

Fig. 3. Regression analysis of total sickness scores (TS) between scenario 1 (clear weather) and scenario 2 (stormy weather). Data points represent the TS scores for individual participants in each scenario, with the red line indicating the best fit illustrating the positive correlation between the conditions. The R-squared value of 0.84 denotes the proportion of variance in TS Scenario 2 that I predictable from TS Scenario 1.

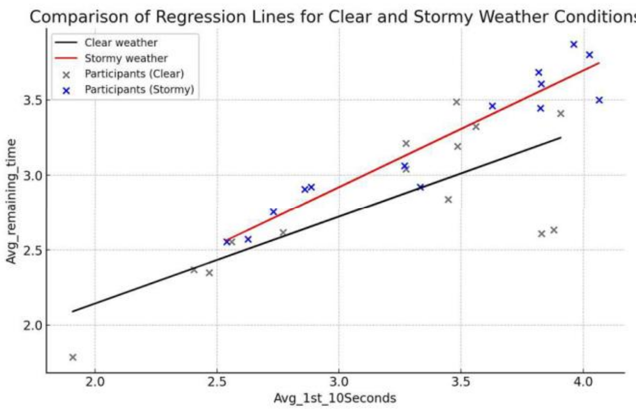

Fig. 4. Scatter plot showcasing the relationship between the average pupil diameter in the first 10 seconds (Avg_1st_10Seconds) and the average remaining time for both clear and stormy weather conditions. Each point represents an individual participant's measurements, with the fitted regression lines illustrating the general trend for each weather condition.

participants generally report greater sickness in stormy conditions. This trend highlights the influence of environmental complexity on simulator sickness.

PD was investigated within the same weather condition while using the HMD (i.e., before flying vs while flying) to ensure being exposed and adapted to illuminance level of the VR environment. To address this, we have conducted more analysis for the average size of the PD for the stormy weather conditions at the start of the experiment (1st 10 seconds), where there is no report of cybersickness, and for the remainder of the experiment. The PD was collected and analysed to investigate the correlation between the cybersickness level and PD size with respect to the two different weather conditions in VR.

Figure 4 illustrates a comparative regression analysis of pupil diameter measurements during the first 10 seconds against the remaining time under clear and stormy weather simulations. The blue and red markers represent individual readings under clear and stormy conditions, respectively. The regression lines indicate a consistent increase in pupil diameter over time for both weather scenarios. Notably, the steeper slope of the line during stormy conditions suggests a more pronounced reaction, potentially attributable to the increased environmental demands of this scenario.

To examine the significance of differences while considering the effects of both condition (clear vs. stormy) and PD (initial vs. remaining time), we calculated paired sample t-tests. The paired t-test for total sickness between clear and stormy conditions yields a t-statistic (t) of -4.04 and a p-value (p) = ~ 0.0014. Given that $p < 0.05$, the difference in total sickness scores is statistically significant. The directionality indicated by the negative t value suggests greater total sickness in stormy conditions as compared to clear conditions.

For the initial pupil diameter (1st 10 seconds), the paired t-test yields a t-statistic (t) of -0.96 and a p-value (p) of approximately 0.3534. This p-value is above the 0.05 threshold, suggesting that there is no statistically significant difference in initial pupil diameter between clear and stormy conditions. The paired t-test for pupil diameter for the remaining time gives a t-statistic (t) of -2.08 and a p-value of approximately 0.0578. This p-value is marginally above the 0.05 threshold. While this suggests that there is no statistically significant difference at the 0.05 level, it is close enough to warrant further investigation or to suggest a possible trend where the pupil diameter for the remaining time might be larger in stormy conditions.

To investigate results further, box plots were constructed to compare the distribution of TS and PD across the two scenarios. Figure 5 illustrates that the median total sickness is higher in the stormy condition (TS_sc2) compared to the clear condition (TS_sc1). The interquartile range (IQR) is wider in the stormy condition, indicating more variability in sickness levels among participants.

Figure 5 also shows that the medians of initial pupil diameters are similar between clear and stormy conditions, though the box for stormy conditions is slightly higher, aligning with the lack of statistical significance found in the t-test. The IQR is slightly wider for clear conditions, suggesting a bit more variability in initial PD measurements under clear conditions. Also, the medians of pupil diameter for the remaining time are higher in the stormy condition with higher spread in the measurements, as indicated by a wider IQR.

In summary, the box plots confirm the results of the statistical tests, showing a significant difference in total. sickness between conditions, no significant difference in initial PD, and a slight, non-significant trend towards higher remaining PD in stormy conditions.

The statistical analysis and visual comparison paint a consistent picture: participants experience more pronounced sickness in stormy conditions, and while their initial pupil response doesn't differ significantly from clear conditions, there is a suggestive trend that the pupil diameter may increase as they continue to be subjected to stormy conditions. This could imply a physiological adaptation or stress response that intensifies with sustained exposure to a challenging environment. These findings underscore the complex interaction between environmental conditions and physiological responses, as evidenced by the changes in total sickness and pupil diameter under varying scenarios.

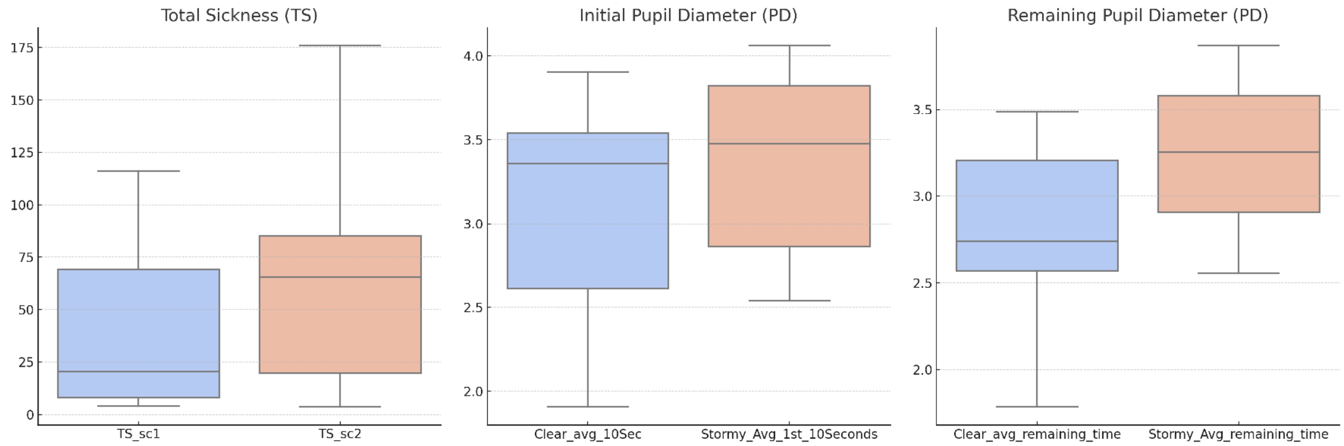

Fig. 5. Box plots comparing the distributions of Total Sickness (TS) and Pupil Diameter (PD) across clear and stormy scenarios. The left panel shows the TS scores for scenarios 1 (clear) and 2 (stormy), indicating higher variability in the stormy condition. The middle and right panels display the initial and remaining PD measurements, respectively, with each box plot representing the central tendency and dispersion of measurements under each environmental condition.

The statistical analysis and visual comparison paint a consistent picture: participants experience more pronounced sickness in stormy conditions, and while their initial pupil response doesn't differ significantly from clear conditions, there is a suggestive trend that the pupil diameter may increase as they continue to be subjected to stormy conditions. This could imply a physiological adaptation or stress response that intensifies with sustained exposure to a challenging environment. These findings underscore the complex interaction between environmental conditions and physiological responses, as evidenced by the changes in total sickness and pupil diameter under varying scenarios.

IV. CONCLUSIONS

This study set out to explore the impact of different weather conditions, specifically clear and stormy, on cybersickness levels in a virtual reality helicopter simulator, with a focus on the correlation between motion sickness and pupil diameter (PD). Our findings indicate a significant increase in total sickness scores during stormy conditions compared to clear conditions, as evidenced by the results from the Simulator Sickness Questionnaire (SSQ). This underscores the influence of environmental complexity on simulator sickness.

Interestingly, while initial pupil diameter measurements did not show a significant difference between the two conditions, there was a suggestive trend of increased pupil diameter over time in stormy conditions. This may indicate a physiological adaptation or stress response that intensifies with sustained exposure to a challenging virtual environment.

The study highlights the complex interplay between environmental conditions and physiological responses in virtual reality settings. It also emphasizes the importance of considering environmental factors when designing VR experiences to minimize cybersickness and enhance user comfort. These findings could be pivotal for future developments in VR technology, particularly in applications where environmental realism and user comfort are paramount, such as pilot training and therapeutic interventions.

By advancing our understanding of the physiological responses to VR environments, this research contributes to the ongoing efforts to optimize VR experiences, balancing the need for realism with the imperative of user well-being. In future studies, more advanced simulators with novel motion cueing algorithms will be used to deliver highly realistic simulated environments to users [44]–[48]. In addition, more advanced AI method will be used for the MS analysis [49] [50].

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REFERENCES

[1]. J. T. Reason and J. J. Brand, Motion sickness. Oxford, England: Academic Press, 1975.

[2]. J. A. Irwin, "THE PATHOLOGY OF SEA-SICKNESS.," Lancet, vol. 118, no. 3039, pp. 907–909, Nov. 1881, doi: 10.1016/S0140-6736(02)38129-7.

[3]. T. G. Dobie, "Motion Sickness," 2019, pp. 1–32.

[4]. G. Bertolini and D. Straumann, "Moving in a moving world: A review on vestibular motion sickness," Frontiers in Neurology, vol. 7, no. FEB. Frontiers Media S.A., p. 14, Feb. 15, 2016, doi: 10.3389/fneur.2016.00014.

[5]. A. Koohestani et al., "A Knowledge Discovery in Motion Sickness: A Comprehensive Literature Review," IEEE Access, vol. 7, pp. 85755–85770, 2019, doi: 10.1109/ACCESS.2019.2922993.

[6]. J. F. Golding, "Motion sickness susceptibility," Auton. Neurosci. Basic Clin., vol. 129, no. 1–2, pp. 67–76, Oct. 2006, doi: 10.1016/j.autneu.2006.07.019.

[7]. J. F. Golding, "Predicting individual differences in motion sickness susceptibility by questionnaire," Pers. Individ. Dif., vol. 41, no. 2, pp. 237–248, Jul. 2006, doi: 10.1016/j.paid.2006.01.012.

[8]. B. Keshavarz and H. Hecht, "Validating an Efficient Method to Quantify Motion Sickness," Hum. Factors J. Hum. Factors Ergon. Soc., vol. 53, no. 4, pp. 415–426, Aug. 2011, doi: 10.1177/0018720811403736.

[9]. J. E. Bos, W. Bles, and E. L. Groen, "A theory on visually induced motion sickness," Displays, vol. 29, no. 2, pp. 47–57, Mar. 2008, doi: 10.1016/j.displa.2007.09.002.

[10]. A. K. T. Ng, L. K. Y. Chan, and H. Y. K. Lau, “A study of cybersickness and sensory conflict theory using a motion-coupled virtual reality system,” Displays, vol. 61, no. August 2019, p. 101922, 2020, doi: 10.1016/j.displa.2019.08.004.

[11]. J. T. Reason, “Motion sickness adaptation: A neural mismatch model,” J. R. Soc. Med., vol. 71, no. 11, pp. 819–829, 1978, doi: 10.1177/014107687807101109.

[12]. L. . Warwick-Evans, N. Symons, T. Fitch, and L. Burrows, “Evaluating sensory conflict and postural instability. theories of motion sickness,” Brain Res. Bull., vol. 47, no. 5, pp. 465–469, Nov. 1998, doi: 10.1016/S0361-9230(98)00090-2.

[13]. A. Kovalev, O. Klimova, M. Klimova, and A. Drozhdev, “The effects of optokinetic nystagmus on vection and simulator sickness,” Procedia Comput. Sci., vol. 176, pp. 2832–2839, 2020, doi: 10.1016/j.procs.2020.09.271.

[14]. N. Duzmanska, P. Strojny, and A. Strojny, “Can simulator sickness be avoided? A review on temporal aspects of simulator sickness,” Frontiers in Psychology, vol. 9, no. NOV. Frontiers Media S.A., Nov. 06, 2018, doi: 10.3389/fpsyg.2018.02132.

[15]. M. R. Chalak Qazani, H. Asadi, T. Bellmann, S. Mohamed, C. P. Lim, and S. Nahavandi, “Adaptive Washout Filter Based on Fuzzy Logic for a Motion Simulation Platform with Consideration of Joints' Limitations,” IEEE Trans. Veh. Technol., vol. 69, no. 11, pp. 12547–12558, 2020, doi: 10.1109/TVT.2020.3023478.

[16]. H. Asadi, T. Bellmann, S. Mohamed, C. P. Lim, A. Khosravi, and S. Nahavandi, “Adaptive Motion Cueing Algorithm Using Optimized Fuzzy Control System for Motion Simulators,” IEEE Trans. Intell. Veh., vol. 8, no. 1, pp. 390–403, 2023, doi: 10.1109/TIV.2022.3147862.

[17]. M. R. C. Qazani et al., “A Neural Network-Based Motion Cueing Algorithm Using the Classical Washout Filter for Comprehensive Driving Scenarios,” IEEE Trans. Intell. Transp. Syst., vol. PP, pp. 1–0, 2023, doi: 10.1109/tits.2023.3340290.

[18]. N. Mohajer, H. Asadi, S. Nahavandi, and C. P. Lim, “Evaluation of the Path Tracking Performance of Autonomous Vehicles Using the Universal Motion Simulator,” Proc. - 2018 IEEE Int. Conf. Syst. Man, Cybern. SMC 2018, pp. 2115–2121, 2018, doi: 10.1109/SMC.2018.00364.

[19]. H. Asadi, S. Mohamed, C. P. Lim, and S. Nahavandi, “Robust Optimal Motion Cueing Algorithm Based on the Linear Quadratic Regulator Method and a Genetic Algorithm,” IEEE Trans. Syst. Man, Cybern. Syst., vol. 47, no. 2, pp. 238–254, 2017, doi: 10.1109/TSMC.2016.2523906.

[20]. A. Mohammadi, H. Asadi, S. Mohamed, K. Nelson, and S. Nahavandi, “MPC-based motion cueing algorithm with short prediction horizon using exponential weighting,” 2016 IEEE Int. Conf. Syst. Man, Cybern. SMC 2016 - Conf. Proc., pp. 521–526, 2017, doi: 10.1109/SMC.2016.7844292.

[21]. H. Asadi, S. Mohamed, K. Nelson, and S. Nahavandi, “A linear quadratic optimal motion cueing algorithm based on human perception,” Australas. Conf. Robot. Autom. ACRA, vol. 02-04- Dece, pp. 2–4, 2014.

[22]. S. Al-Serri et al., “Implementation of the Grasshopper Optimisation Algorithm to Optimize Prediction and Control Horizons in Model Predictive Control-based Motion Cueing Algorithm,” Conf. Proc. - IEEE Int. Conf. Syst. Man Cybern., vol. 2022-Octob, pp. 3317–3323, 2022, doi: 10.1109/SMC53654.2022.9945416.

[23]. M. R. C. Qazani, H. Asadi, C. P. Lim, S. Mohamed, and S. Nahavandi, “Prediction of Motion Simulator Signals Using Time-Series Neural Networks,” IEEE Trans. Aerosp. Electron. Syst., vol. 57, no. 5, pp. 3383–3392, Oct. 2021, doi: 10.1109/TAES.2021.3082662.

[24]. O. X. Kuiper, J. E. Bos, and C. Diels, “Vection does not necessitate visually induced motion sickness,” Displays, vol. 58, no. October 2018, pp. 82–87, 2019, doi: 10.1016/j.displa.2018.10.001.

[25]. B. Keshavarz, B. Murovec, N. Mohanathas, and J. F. Golding, “The Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ): Estimating Individual Susceptibility to Motion Sickness-Like Symptoms When Using Visual Devices,” Hum. Factors J. Hum. Factors Ergon. Soc., p. 001872082110086, 2021, doi: 10.1177/00187208211008687.

[26]. L. Picu, E. Rusu, and M. Picu, “Evaluation of human exposure to whole-body vibration-verification method of stevens's power law,” Int. Multidiscip. Sci. GeoConference Surv. Geol. Min. Ecol. Manag. SGEM, vol. 18, no. 5.2, pp. 413–420, 2018, doi: 10.5593/sgem2018/5.2/S20.055.

[27]. M. Algumaei, I. Hettiarachchi, R. Veerabhadrappa, and A. Bhatti, “Physiological Synchrony Predict Task Performance and Negative Emotional State during a Three-Member Collaborative Task,” Sensors, vol. 23, no. 4, 2023, doi: 10.3390/s23042268.

[28]. S. Alsanwy, H. Asadi, A. Alqumsan, S. Mohamed, D. Nahavandi, and S. Nahavandi, “The Effects of Different Body Positions on Human Physiological Responses Using Universal Motion Simulator,” Conf. Proc. - IEEE Int. Conf. Syst. Man Cybern., pp. 1209–1214, 2021, doi: 10.1109/SMC52423.2021.9658601.

[29]. M. A. Khan, H. Asadi, T. Hoang, C. P. Lim, and S. Nahavandi, “Measuring Cognitive Load: Leveraging fNIRS and Machine Learning for Classification of Workload Levels,” in Journal of the Society of Mechanical Engineers, vol. 90, no. 823, 2024, pp. 313–325.

[30]. M. Jäger, N. Gruber, R. Müri, U. P. Mosimann, and T. Nef, “Manipulations to reduce simulator-related transient adverse health effects during simulated driving,” Med. Biol. Eng. Comput., vol. 52, no. 7, pp. 601–610, Jul. 2014, doi: 10.1007/s11517-014-1162-x.

[31]. S. V. G. Cobb, S. Nichols, A. Ramsey, and J. R. Wilson, “Virtual Reality-Induced Symptoms and Effects (VRISE),” Presence Teleoperators Virtual Environ., vol. 8, no. 2, pp. 169–186, Apr. 1999, doi: 10.1162/105474699566152.

[32]. K. M. Stanney, D. S. Lanham, R. S. Kennedy, and R. Breaux, “Virtual Environment Exposure Drop-Out Thresholds,” Proc. Hum. Factors Ergon. Soc. Annu. Meet., vol. 43, no. 22, pp. 1223–1227, Sep. 1999, doi: 10.1177/154193129904302212.

[33]. T. G. Dobie, “The Use of Non-pharmacological Therapy,” 2019, pp. 219–245.

[34]. S. Palmisano, R. Mursic, and J. Kim, “Vection and cybersickness generated by head-and-display motion in the Oculus Rift,” Displays, vol. 46, pp. 1–8, Jan. 2017, doi: 10.1016/j.displa.2016.11.001.

[35]. B. D. Lawson and others, “Motion Sickness Symptomatology and Origins.” 2014.

[36]. N. Sugita et al., “Quantitative evaluation of effects of visuallyinduced motion sickness based on causal coherence functions between blood pressure and heart rate,” Displays, vol. 29, no. 2, pp. 167–175, Mar. 2008, doi: 10.1016/j.displa.2007.09.017.

[37]. H. Chen, A. Dey, M. Billinghurst, and R. W. Lindeman, “Exploring pupil dilation in emotional virtual reality environments,” Int. Conf. Artif. Real. Telexistence Eurographics Symp. Virtual Environ. ICAT-EGVE 2017, pp. 169–176, 2017, doi: 10.2312/egve.20171355.

[38]. A. Ozkan and U. Celikcan, “The relationship between cybersickness and eye-activity in response to varying speed, scene complexity and stereoscopic VR parameters,” Int. J. Hum. Comput. Stud., vol. 176, no. July 2022, p. 103039, 2023, doi: 10.1016/j.ijhcs.2023.103039.

[39]. R. Islam, K. Desai, and J. Quarles, “Cybersickness Prediction from Integrated HMD's Sensors: A Multimodal Deep Fusion Approach using Eye-tracking and Head-tracking Data,” no. August, 2021.

[40]. H. Oyamada et al., “A pilot study on pupillary and cardiovascular changes induced by stereoscopic video movies,” J. Neuroeng. Rehabil., vol. 4, pp. 1–7, 2007, doi: 10.1186/1743-0003-4-37.

[41]. B. Y. Koo, M. H. Jang, Y. C. Kim, and K. C. Mah, “Changes in the subjective fatigue and pupil diameters induced by watching LED TVs,” Optik (Stuttg)., vol. 164, pp. 701–710, 2018, doi: 10.1016/j.ijleo.2018.03.077.

[42]. S. Park, S. Mun, J. Ha, and L. Kim, “Non-contact measurement of motion sickness using pupillary rhythms from an infrared camera,” Sensors, vol. 21, no. 14, 2021, doi: 10.3390/s21144642.

[43]. R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, “Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness,” Int. J. Aviat. Psychol., vol. 3, no. 3, pp. 203–220, Jul. 1993, doi: 10.1207/s15327108ijap0303_3.

[44]. M. R. Chalak Qazani, H. Asadi, S. Mohamed, C. P. Lim, and S Nahavandi, “A Time-Varying Weight MPC-Based Motion Cueing Algorithm for Motion Simulation Platform,” IEEE Trans. Intell. Transp. Syst., vol. 23, no. 8, pp. 11767–11778, 2022, doi: 10.1109/TITS.2021.3106970.

[45]. S. Pedrammehr, H. Asadi, and S. Nahavandi, “The forced vibration analysis of hexarot parallel mechanisms,” Proc. IEEE Int. Conf. Ind. Technol., vol. 2019-Febru, pp. 199–204, 2019, doi: 10.1109/ICIT.2019.8755207.

[46]. H. Asadi, “Human perception-based washout filtering,” 2022, [Online]. Available: https://dro.deakin.edu.au/articles/thesis/Human_perceptionbased_ washout_filtering/21107281.

[47]. M. R. C. Qazani, H. Asadi, S. Mohamed, C. P. Lim, and S Nahavandi, “An optimal washout filter for motion platform using neural network and fuzzy logic,” Eng. Appl. Artif. Intell., vol.108, no. December 2021, p. 104564, 2022, doi: 10.1016/j.engappai.2021.104564.

[48]. M. R. Chalak Qazani et al., “A New Prepositioning Technique of a Motion Simulator Platform Using Nonlinear Model Predictive Control and Recurrent Neural Network,” IEEE Trans. Intell. Transp. Syst., vol. 23, no. 12, pp. 23268–23277, 2022, doi: 10.1109/TITS.2022.3195964.

[49]. M. R. Chalak Qazani, H. Asadi, M. Al-Ashmori, S. Mohamed, C. P. Lim, and S. Nahavandi, “Time series prediction of driving motion scenarios using fuzzy neural networks: ∗ Motion Signal Prediction Using FNNs,” 2021 IEEE Int. Conf. Mechatronics, ICM 2021, 2021, doi: 10.1109/ICM46511.2021.9385693.

[50]. S. Alsanwy, H. Asadi, M. Reza, C. Qazani, and S. Mohamed, “A CNN-LSTM Based Model to Predict Trajectory of Human- Driven Vehicle,” 2023 IEEE Int. Conf. Syst. Man, Cybern., pp. 3097–3103, 2023, doi: 10.1109/SMC53992.2023.10394243.