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Motion Sickness Minimization Alerting System Using The Next Curvature Topology

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***Abstract*— Current intelligent car prototypes increasingly move to become autonomous where no driver is required. If an automated vehicle has rearward and forward facing seats and none of the passengers pay attention to the road, they increasingly experience the motion sickness because of the inability of passengers to anticipate the future motion trajectory. In this paper, we focus on anticipatory audio and video cues using pleasant sounds and a Human Machine Interface to display and inform the passengers about the upcoming trajectories that may lead to make the passengers sick. To be able to anticipate the next moves, we require an evaluation system of the next 1 kilometer of the road using the map. The road is investigated based on the amount of the turns and the maximum speed allowed that lead to lateral accelerations that is high enough based on Motion Sickness Dose Value to make the passengers sick. The system alerts the passengers through a Human Machine Interface to focus on the road for prevention of the Motion Sickness. We evaluate our method by using Motion Sickness Dose Value. Based on this work, we can prevent the sickness due to lateral accelerations by making the passengers to focus on the road and decrease the vestibular conflict.**

Keywords— Motion Sickness, Autonomous Driving, Comfort, embedded control systems, Human Machine Interface.

I. Introduction

Vehicle control of the semi- and full Autonomous Vehicles should consider the passengers' stress and try to maintain their comfort level [1]. Furthermore, there is a tight relationship between comfort and trust, as well as the automated vehicles' acceptance [2].

One of the wide recognized comfort issues for the passengers probably is Motion Sickness. It starts appearing with headache, pallor, sweating, nausea, vomiting, and disorientation, and they are calculated by Vestibule Ocular Reflex (VOR) parameters, Physiological signals, and Posture stability. To mitigate it, Immersive Experience, Posture and vehicle controllability, and instance visual cues can be used [3].

The potential sources of AV motion sickness can be divided into five groups, namely, loss of controllability and loss of anticipation of motion direction, variation in horizontal and vertical acceleration, Head downward inclination, posture instability, and lack of synchronization between virtual motion and the vehicle motion profile [3]. The motion sickness is mostly occurred by a conflict between visual and vestibular inputs. However, the loss of controllability over one's movements and unability to predict the movement direction are also crucial in motion sickness [4]. In the most of the cases, the motion sickness experience is for the passengers and the drivers rarely experience it [4]. Possible countermeasures are categorized in two groups: prevention solutions and mitigation solutions.

One of the general ideas for overcoming the motion sickness is using human senses to provide sufficient situation awareness (SA). In the contexts of automotive and driving, SA is recognized as awareness of the current position of the car in relation to its destination, the relative positions, and behavior of other road users and potential hazards, and knowing how these critical variables are likely to change in the near future [5]. This is because the drivers less often get sick since they are able to anticipate the next moves [6] and can predict required actions based on previous experiences.

If a passenger becomes aware of the required information about the road, we can avoid the sensory mismatch. One of the required information is the immediate intention of the AV that involves variation in the lateral and longitudinal forces. This information can be presented shortly before an important situation that is about to happen (for example when a junction is approaching). The virtual modality is one of the ways that the information can be delivered [7]. Furthermore, the informative auditory lowers the average illness ratings respect to the condition without informative cues [8].

We contribute to research with the original design of a minimization system that predicts the road characteristics in one kilometer ahead and using the HMI instructions for the passengers to be ready for the next potential motion sickness. The system calculates in real time using an NVidia AGX and monitors the road all the time. The system is designed in a way that prevents the unnecessary interactions with the passengers both visual and sound cues and the system is on a real vehicle with a motion prediction algorithm to describe the next moves. Despite most of the works that are in a simulation phase, our work is tested in real vehicles in real scenarios. To evaluate our work we use Motion Sickness Dose Value (MSDV) [9] for the evaluation. Our contributes can be categorize in the following groups:

- A real time system that calculates the potential lateral accelerations based on the road characteristics in the next 1 km;
- An alert system that tries to interact with the passengers only at the time of the existing the potential motion sickness ahead and tries to minimize the interactions;
- Defining a new equation to calculate the motion sickness in the curves;

- The system can be used in fully autonomous vehicles as well as vehicles with less autonomy.

In the following sections, we first review the state-of-the-art in motion sickness. Then we describe the details of our Human Machine Interface (HMI) and sound profile. Finally, we show how we implemented it and discuss the experimental results with respect to the reference metrics of motion sickness.

II. MOTION SICKNESS IN LITERATURE

In the recent years some efforts have been done to mitigate and minimize the motion sickness. These works can be categorized in two different groups. The first group tries to minimize the MS by having a new motion planner with a library of costs. In this regard, In [10], five different main physical characteristics that can be effective on motion sickness, and defining them in a function cost, to improve quality passengers' experience and minimize the Motion Sickness to vehicle passengers is considered. In [1] the costs of consisting of progress, comfort, and safety are utilized for the evaluation of the strategies generated by the three modules of distance keeper, lane selector, and merge planner. In [4], on investigation with two strategies for decreasing the visual-vestibular conflict while watching videos is conducted. The first approach locates visual stimuli on or around the video screen to mimic the perceived motion and forces of the moving vehicle. The second method tries to control the position of displayed images synchronized with passenger's head motions produced by vehicle acceleration/deceleration and vehicle motions, then provides a video that appears to be stabilized in relation to the movement of the vehicle. In [11], they generate the optimal Path Planning using Clothoid Curves to increase the comfort of the passengers. They use the second clothoid length, the straight line to the goal at the end, made up of the first clothoid length, and the squared distance along the curve as their costs to control. To minimize the MSDV in autonomous vehicles, [12] presents an application of motion planning [12]. On the other hand, in the second group, the researchers try to have a anticipation alert to the passengers, so their brain will be ready to start the maneuvers. In this regard, in [13], they investigate the effects of peripheral information about upcoming maneuvers through a vibrotactile display in increasing the fully-automated driving car passengers' awareness of situations and mitigating their motion sickness level. This study concludes that in order to mitigate motion sickness inside a fully-automated driving car, more specific information need to be included in the peripheral information. In [14], they have progressed a prototype of a human– machine interface (HMI) that presents anticipatory ambient light cues for the AV's next turn to the passenger. The HMI prototype was proven to be effective regarding highly susceptible users. In [8] average illness ratings were significantly lower for the condition that contained informative auditory cues, as compared to the condition without informative cues. One second in advance of each displacement a sound clip was played over headphones communicating either "forward" or "backward" in the native language of the participant. In addition, recently, [7] resulted that if there is an additional effect of augmented visual stimulion MS, the effect is at best small. Therefore, having an augmented visual stimulion is not in our plan.

Although using different methods can lower the MS level, most of them are not tested in a real autonomous vehicle. Furthermore, the sound cues should be in a way that the passengers do not disturb. Indeed, the visual cues should be in a way that shows the regular view of the vehicle not an augmented one [7]. In this regard, we focus on anticipatory audio and video cues using pleasant sounds and a Human Machine Interface to display and inform the passengers about the upcoming trajectories that may lead to make the passengers sick. To be able to anticipate the next moves, we require an evaluation system of the next 500 meters of the road using the map. The road is investigated based on the amount of the turns and the maximum speed allowed that lead to lateral accelerations that is high enough based on Motion Sickness Dose Value to make the passengers sick. The system alerts the passengers through a Human Machine Interface to focus on the road for prevention of the Motion Sickness.

III. CURVATURE AND LATERLA ACCELERATION ANALYSIS

For having a correct lateral acceleration prediction, we need to the speed along with the maximum superelevation rate and the maximum allowable side friction demand (assumed in the Green Book [17] to be the friction between the tires and pavement) determine the minimum radius of curvature for each design speed [15]. Equation 1 is used to determine the minimum radius of a circular horizontal curve.

$$R_{min} = \frac{V_d^2}{15(e_{max} + f_{max})} \quad (1)$$

where,

R_{min} = minimum radius of curvature (ft),

V_d = design speed (mph),

e_{max} = specified maximum superelevation elevation rate (fit/100 ft),

f_{max} = specified maximum side friction demand.

The tendency of a vehicle to either skid off the road or overturn must be resisted by either the friction developed between the vehicle tires and the pavement or the vehicle's roll stability, respectively. A vehicle will skid off the road when the side friction demand exceeds tire/pavement friction. Also, a vehicle will overturn if the unbalanced lateral acceleration exceeds the rollover threshold of the vehicle [16].

According to the Green Book [17], the maximum available side friction factor (friction developed by the tire-pavement interaction) should not be used directly for the design of a horizontal curve. Instead, the value used in design should be a percentage of the maximum available side friction factor that can be used with comfort and safety by the majority of drivers. This limiting value is described as the lateral acceleration that is sufficient to cause the driver to experience discomfort and to instinctively avoid higher speed. Accordingly, the speed at which a driver feels discomfort due to the lateral acceleration generated while traversing a curve can be accepted as a design control for the maximum allowable amount of the side friction factor.

The Green Book [17] provides side friction factors (J) for low-speed and high-speed design of roadways. Currently, American Association of State Highway and Transportation Officials (AASHTO) bases these recommended values on the results of various. AASHTO's recommended maximum allowable side friction factors for low-speed roads vary with the design speed from 0.38 at 10 mph (16 km/h) to 0.14 at 45 mph (72 km/h), and then vary directly with the design speed to 0.08 at 80 mph (128 km/hr). These values for high speed provide a "reasonable margin of safety at high speeds." The values for low-speed design are higher since drivers are more tolerant of discomfort at lower speeds.

The coefficients of friction for forward skid on wet concrete pavement with tires having new treads. The wet pavements have lower coefficients of friction than dry pavement. Currently, the Green Book defines the margin of safety in horizontal curve design as the difference between f_{design} and f at impending skid. These values for at impending skid are assumed to be the ultimate side friction values for good tires on wet concrete pavement. These conditions are considered sufficiently representative for a meaningful analysis.

A. The Point Mass Model

Under the AASHTO policy, a point mass is used to represent a vehicle on a horizontal curve. In this model, the vehicle's suspension is ignored. From basic physics, the lateral acceleration of a point mass traveling on a circular path at a constant speed can be represented by the following relationship:

$$a = \frac{V^2}{15R} \tag{2}$$

where,

a = lateral acceleration (g)

V = vehicle speed (mph)

R = radius of curve (ft)

The lateral acceleration experienced by the vehicle is relative to g which is equal to 32.2 ft/s^2 (9.8 m/s^2).

In the Point Mass Model, all points in a vehicle are assumed to have the same acceleration; in other words, the entire vehicle is a "point mass." Consider in Fig. 1.

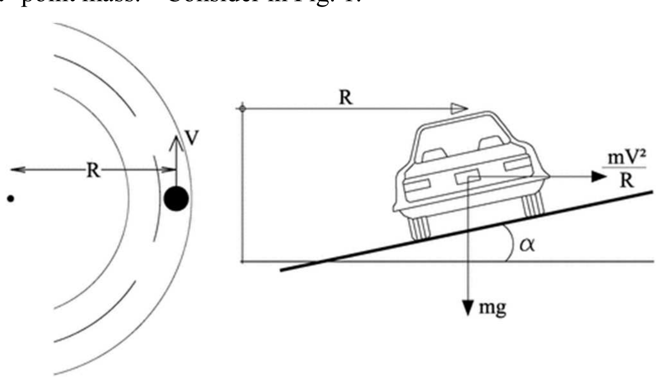

Fig. 1. The mass point of the vehicle and the radius (R) of the curve.

where a vehicle is represented as a point with mass, m, and weight, mg, traversing at speed, V, around a curve with radius, R, and superelevation, e. Summing forces along the superelevated plane results in the following equation:

$$fN + mgsin\theta = \frac{mV^2}{R}cos\theta \tag{3}$$

where,

f = side friction demand,

N = normal force resulting from force of vehicle due to gravity, mg,

W = force of vehicle due to gravity, mg,

g = acceleration due to gravity, 32.3 fit/s2 (9.81 m/s2),

θ = angle resulting from superelevation, e.

Solving for/ results in

$$f = \frac{\frac{mV^2}{R}cos\theta - mgsin\theta}{N} \tag{4}$$

Cancelling units, using substitution and small angle approximation where $cos\theta$ is 1 and $sin\theta$ is e, results in

$$f = \frac{V^2}{15R} - e \tag{5}$$

B. Lateral acceleration

When a vehicle moves in a circular path, it undergoes a centripetal acceleration that acts toward the center of curvature. This acceleration is sustained by a component of the vehicle's weight related to the roadway superelevation, by the side friction developed between the vehicle's tires and the pavement surface, or by a combination of the two. Centripetal acceleration is sometimes equated to centrifugal force. However, this is an imaginary force that motorists believe is pushing them outward while cornering when, in fact, they are truly feeling the vehicle being accelerated in an inward direction. In horizontal curve design, "lateral acceleration" is equivalent to "centripetal acceleration"; the term "lateral acceleration" is used in this policy as it is specifically applicable to geometric design.

Based on [18], large radius curves, the drivers limit their speed by both their comfortable lateral acceleration and speed environment. On small curves, a comfortable or "easy ride" corresponded to an experienced lateral acceleration of 0.35g to 0.40g.

Based on the radius and maximum velocity defined in the road, we may find the actual acceleration that will be occurred in the curve and calculate the MSDV based on it.

C. Radius calculation

As discussed, for having the lateral acceleration in vehicle, we need the radius of the curve. To calculate the radius, we use the pure pursuit method. To use it we need to choose a proper look ahead distance, based on the Fig. 2.

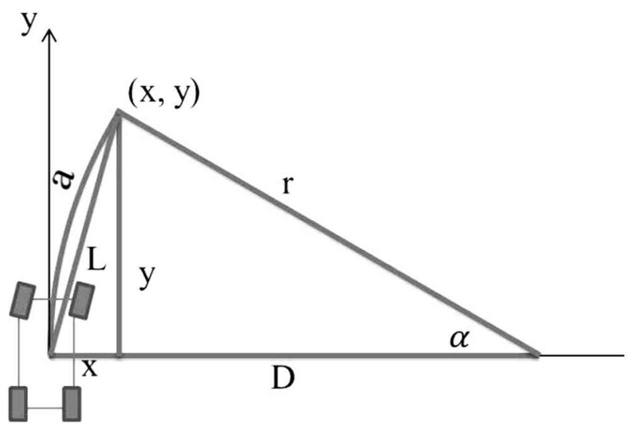

Fig. 2. Pure pursuit model geometry. This model is used to calculate the radius of the curvature. Based on the curvature's radius along with the velocity and acceleration in the curvature, we will be able to calculate the MSDV and IR.

The x and y axis construct the coordinate system of machine. The point (x, y) is a point some distance ahead of the machine. The L is the length of the cord of the arc connecting the origin to the point (x, y). r is the radius of curvature of the arc and a is the arc length of α angle. The relationship of x, L and r is as follows:

$$D + x = r \quad (6)$$

$$D^2 + x^2 = r \quad (7)$$

$$x^2 + y^2 = L^2 \quad (8)$$

From Eq. (6), Eq. (7) and Eq. (8),

$$r^2 - 2rx + x^2 + y^2 = r^2 \quad (9)$$

$$r = \frac{L^2}{2x} \quad (10)$$

$$a = \frac{\alpha}{360}(2\pi r) \quad (11)$$

By choosing a look-ahead distance and calculating the path error x, the radius of the curvature required to get the machine on the required path can be calculated

D. Motion Sickness Dose Value

The total MSDV resulted from lateral and longitudinal motion is given as (Standard, 1987):

$$MSDV = \sqrt[2]{\int_0^T (a_{x,w}(t))^2} + \sqrt[2]{\int_0^T (a_{y,w}(t))^2} \quad (12)$$

Where $a_{y,w}(t)$ and $a_{x,w}(t)$ are the frequency weight acceleration in the lateral and longitudinal direction.

$$a_{x,w}(t) = a_x(t) \times W_f \quad (13)$$

$$a_{y,w}(t) = a_y(t) \times W_f \quad (14)$$

where $a_x(t)$ is the longitudinal acceleration and $a_y(t)$ is the lateral one. In Standard 6841 [9] W_f is defined as the weighting factor for evaluating low frequency motion with respect to motion sickness. Since we consider only the lateral accelerations, we consider just $a_y(t)$ in our calculations. From the standards [9], [19], a simple linear approximation between mean passenger illness rating and MSDV is defined as:

$$IR = K \times MSDV \quad (15)$$

where IR is defined as the predicted illness rating and K is an empirically derived constant. Based on [9] and [19], the illness rating value is in four levels; The illness rating of 0 demonstrates the feeling fine, 1 demonstrates slightly unwell, 2 demonstrates quite ill, and 3 demonstrates absolutely dreadful.

E. Motion Sickness in the curves

The previous calculations show that we can calculate the MSDV using the lateral accelerations and the lateral accelerations can be defined based on the velocity and the radius of the curve. To achieve a single formula, we neglect the accelerations in x axis since we assume that we will have constant velocity in the curves. Therefore, MSDV will be:

$$MSDV = \sqrt[2]{\int_0^T (a_y(t) \times W_f)^2} \quad (16)$$

Since we considered a constant velocity on the curve, our acceleration will not change in the curve and based on the Equation (2), the Equation (16) we will have:

$$MSDV = \frac{V^2}{15R} \times W_f \sqrt[2]{T} \quad (17)$$

With this new MSDV equation that we have defined, we can calculate the MSDV before each curve. By calculating each MSDV before the curve, we will be able to decide whether it would be a road with potential motion sickness or not.

IV. The Experimental Setup

For the experimental setup of our work, we used a simulator sending the data constantly to our Human Machine Interface (HMI) and embedded system to communicate with the passengers. The embedded platform has the responsibility of calculating the potential MSDV based on the next lateral acceleration and alert the passengers through the HMI about the upcoming condition that may lead to Motion Sickness. Fig. 3 demonstrates the diagram of our system.

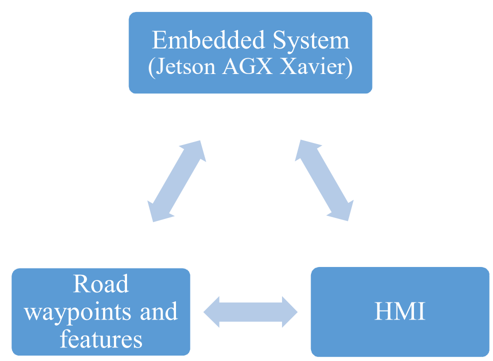

Fig. 3. The diagram of the Motion Sickness minimization system.

A. Embedded system

We targeted NVIDIA Jetson AGX Xavier that is representative of the next-generation AV Domain Controller as our embedded platform. This embedded platform has a GPGPU of 512-core Volta along with Tensor Core and a CPU of ARM 8-core v8.2 64-bit and would be a suitable choice for our system.

B. Human Machine Interface

We used a Human Machine Interface (HMI) to interact with the passenger. We do this on a window with a message alerting the passenger about starting to focus on the upcoming road. In this way, the passengers know about the potential upcoming motion sickness and try to concentrate on the road to minimize it. Fig. 4 shows the HMI we used to interact with the passengers.

This HMI consists of several parts to show the information. First, it continuously shows the vehicle's velocity. It also needs to show the map of the upcoming curvatures. Therefore, the online place of the vehicle is in the HMI. Since the maximum velocity needs to be included in the MSDV formula, we show it on the HMI so the passengers would be aware of the maximum velocity. Finally, whenever it is needed, the HMI shows the alert message. These properties make our system compatible with the vehicles with different autonomy levels.

Fig. 4. The HMI that interacts with the passengers. In this HMI we try to alert the passengers about the upcoming roads with potential motion sickness.

C. Road waypoints and features

For the testing of the work, we used the ego_pose of nuScences dataset [20]. The nuScenes dataset is the first dataset to carry the full autonomous vehicle sensor suite: 6 cameras, 5 radars and 1 lidar, all with full 360-degree field of view. nuScenes comprises 1000 scenes, each 20s long and fully annotated with 3D bounding boxes for 23 classes and 8 attributes. We used the ego pose of the dataset and gathered all the necessary information to test our work. The ego_pose has been extracted by the MATLAB drivingScenario tool. Then we created the waypoints by its poses. The features that should be received by the embedded system are the width and the waypoints of the center line of the road. The waypoints should include x, y, and z dimensions. Based on this information and the theory that we mentioned before, we calculate the potential lateral acceleration and MSDV.

V. Tests and Results

Testing of our work was done by the nuScenes dataset and exporting the MSDV into the simulator. In MATLAB we extracted the results of the MSDV and exported them to the simulator. If the illness rating is more than 1, any symptoms, however slight [19], the HMI would show the MSDV alert.

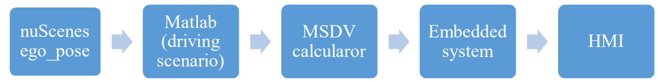

Fig. 5. The test procedure that starts with the getting the ego_pose of the nuScenes dataset. The ego_pose would be imported to Matlab and create the scenario by the driving Scenario tool. Then, the MSDV would be calculated in the Embedded system and sends the results to the HMI to show if the Motion Sickness is coming or no.

A. The road testing

The tests utilized the data acquired from the road dataset. The Fig. 6. shows one of the tests that have been conducted through a real waypoint from dataset. In the Fig. 5. can be seen a curvature that has been distinguished as a potential curve of motion sickness.

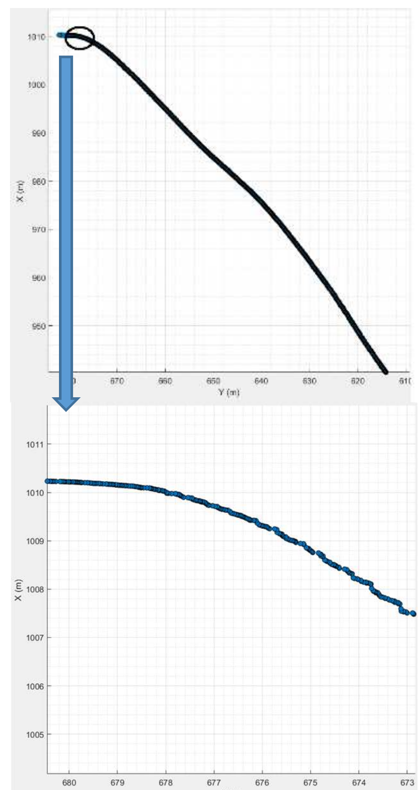

Fig. 6. The potential curve of motion sickness. Each curvature that is a potential curve for the motion sickness, is investigated by the possible MSDV and IR based on the maximum velocity and the curvature's radius.

VI. Conclusion

In this paper, we demonstrated a novel way to alert the passengers for the upcoming motion sickness. This system aims the compatibility for using in fully or semi-autonomous vehicles. The new equation of the motion sickness made us enable to calculate the level of the motion sickness by the lateral acceleration for the next curvatures. The alerting system can help the passengers to prevent the motion sickness.

This work by its functionalities enables us to extend it in a real world. For the future improvements, we plan to use it in the real vehicles by the online mapping. The online map services, like google maps, would help us to use the ahead positions and with those positions and our equations we will be able to calculate the MSDV and alert the passengers online.

REFERENCES

[1] J. Elsner, "Optimizing passenger comfort in cost functions for trajectory planning," arXiv.org, 16-Nov-2018. [Online]. Available: https://arxiv.org/abs/1811.06895.

[2] H. Bellem, B. Thiel, M. Schrauf, en J. F. Krems, "Comfort in automated driving: An analysis of preferences for different automated driving styles and their dependence on personality traits", Transp. Res. Part F Traffic Psychol. Behav., vol 55, bll 90–100, Mei 2018.

[3] J. Iskander et al., "From car sickness to autonomous car sickness: A review", Transp. Res. Part F Traffic Psychol. Behav., vol 62, bll 716–726, Apr 2019.

[4] M. Sivak en B. Schoettle, Motion sickness in self-driving vehicles. University of Michigan, Ann Arbor, Transportation Research Institute, 2015.

[5] R. Sukthankar, "Situation awareness for tactical driving", Doctoral dissertation, Carnegie Mellon University, 1997.

[6] A. Rolnick en R. E. Lubow, "Why is the driver rarely motion sick?" The role of controllability in motion sickness, Ergonomics, vol 34, no 7, bll 867–879, Jul 1991.

[7] K. N. de Winkel, P. Pretto, S. A. E. Nooij, I. Cohen, en H. H. Bülthoff, "Efficacy of augmented visual environments for reducing sickness in autonomous vehicles", Appl. Ergon., vol 90, no 103282, bl 103282, Jan 2021.

[8] O. X. Kuiper, J. E. Bos, C. Diels, en E. A. Schmidt, "Knowing what's coming: Anticipatory audio cues can mitigate motion sickness", Appl. Ergon., vol 85, no 103068, bl 103068, Mei 2020.

[9] B. S. I. Standard, 6841, Guide to Measurement and Evaluation of Human Exposure to Whole-Body Mechanical Vibration and Repeated Shock. London, UK: BSI, 1987.

[10] I. Moazen and P. Burgio, "A Full-Featured, Enhanced Cost Function to Mitigate Motion Sickness in Semi-and Fully-autonomous Vehicles", 2021, bll 497–504.

[11] E. Lambert, R. Romano, en D. Watling, "Optimal path planning with clothoid curves for passenger comfort", in Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems, Heraklion, Crete, Greece, 2019.

[12] Z. Htike, G. Papaioannou, E. Velenis, en S. Longo, "Motion planning of self-driving vehicles for motion sickness minimisation", in 2020 European Control Conference (ECC), Saint Petersburg, Russia, 2020.

[13] N. M. Yusof, J. Karjanto, J. M. B. Terken, F. L. M. Delbressine, en G. W. M. Rauterberg, "Gaining situation awareness through a vibrotactile display to mitigate motion sickness in fully-automated driving cars", International Journal of Automotive and Mechanical Engineering, vol 17, no 1, bll 7771–7783, 2020.

[14] R. Hainich, U. Drewitz, K. Ihme, J. Lauermann, M. Niedling, en M. Oehl, "Evaluation of a human–machine interface for motion sickness mitigation utilizing anticipatory ambient light cues in a realistic automated driving setting", Information (Basel), vol 12, no 4, bl 176, Apr 2021.

[15] D. R. Merrit, "Safe Speeds on Curves: A Historical Perspective of the Ball Bank Indictor". ITE Journal, Vol. 58, No. 9, 1988, pp. 15–19.

[16] D. W. Harwood, and J. M. Mason, "Horizontal Curve Design for Passsenger Cars and Trucks", In Transportation Research Record 1445, TRB, National Research Council, Washington, D. C., 1994, pp. 22–33

[17] G. BOOK, "CONCEPTS AND RATIONALE FOR STREAMING SERVICES OVER BUNDLE PROTOCOL", 2018.

[18] F., E., and F. Navin, "Automobiles on horizontal curves: experiments and observations", Transportation Research Record 1628, no. 1 (1998): 50-56.

[19] B. Anon, "Mechanical vibration and shock-evaluation of human exposure to whole-body vibration", International Organization for Standardization, ISO 2631 (1997).

[20] H. Caesar et al., "nuScenes: A multimodal dataset for autonomous driving," in Proc. IEEE Conf. Comput. Vis. Pattern Recognit., 2020, pp. 11621–11631