Virtual Simulation of Driver's Head Tilting

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I. INTRODUCTION

As more advanced driver assistance systems (ADAS) sensors are introduced to vehicle design, virtual simulations become one of the most effective ways to validate their performances. There are three main components for traffic safety, 1) Vehicle, 2) Environment, and 3) Human Driver. The virtual modelling of the first two components, such as ADAS sensors, vehicle dynamics, driving roadway and weather conditions has already reached a level of enough fidelity and precision to supersede parts of or whole real physical test. On the other hand, the virtual models of the human driver or even passenger are relatively in its premature stage due to its non-deterministic characteristics in behaviour and physique, which brings a large amount of uncertainty and thus hinders becoming a part of the standardised design process.

Reference [1-2] presented an active human body model that simulates the initial muscle tensing and the awareness level by introducing damping and neural delay time at articulated joints. A proportional-integral-derivative (PID) closed-loop controlled active joint torques were also added to represent the reflexive reaction of vehicle passengers to maintain a stable seated posture. This modelling approach based on a lumped network Modelica language was verified and validated against the head and chest kinematics measured at the test series of single lane change manoeuvre [2].

As an extension of the previous study [2], the kinematics of vehicle driver was virtually simulated especially focused on the head tilting when going around corners. In the aspect of dynamic seated posture control during a normal driving phase, the primary difference between the driver and passengers is hand position and steering action. The motion of the driver's upper body has better support and control via the stretched arm and hands by holding the steering wheel than passengers whose hands are normally placed on their laps. However, occupant head, the uppermost body segment in the open-chain multi-body articulation of the seated occupant has no direct support for both driver and passenger. However, the direction of the head tilting of the driver when going around corners is known to be quite different than for passengers. Reference [3] found that the driver's head tilt was highly correlated with the visually available estimate of the curvature of the road (r^2 = 0.86) but not with the centripetal force ($r^2 < 0.1$) while the passengers' head tilts were inversely correlated with the lateral forces (r^2 = 0.3 - 0.7) and seem to reflect a passive sway.

II. METHODS

A real driving test at our repository was utilised to validate the result from a virtual simulation. The vehicle kinematics of 40sec driving along the 1km long reverse curved road with 90kph speed was virtually reconstructed to estimate the steering angle profile. The measured basic vehicle kinematics, such as driving speed (V), longitudinal and lateral accelerations (A_x, A_y), Yaw rate (ω_Z) and reconstructed steering angle were used as input conditions for the driver model to simulate the head kinematics.

The sign convention in this paper is shown in Fig. 1.

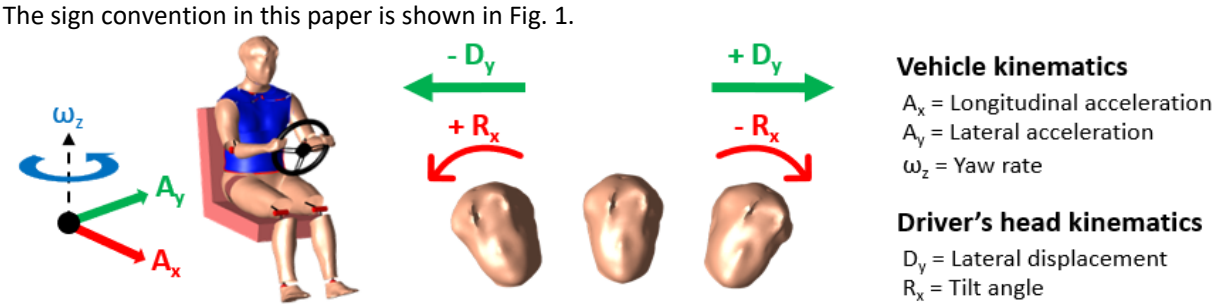

Fig. 1. Sign convention.

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Real Driving Test

Fig. 2 shows the driving road map (Google) and measured vehicle kinematics at the real driving test. The driving test was performed by a certified driver (42 years old male, 72kg, 173cm) at a public road. The vehicle accelerations and rotational rate were measured by the Inertial Measurement Unit (Shimmer3 IMU) and low pass filtered by 10Hz. The driving speed was obtained from the 1Hz GPS log. As can be seen in Fig. 2, the most perturbing reverse curved road segment was between 20-30 seconds which produced peak lateral accelerations (A_y) linearly shifting from +8 to -9 m/s^2.

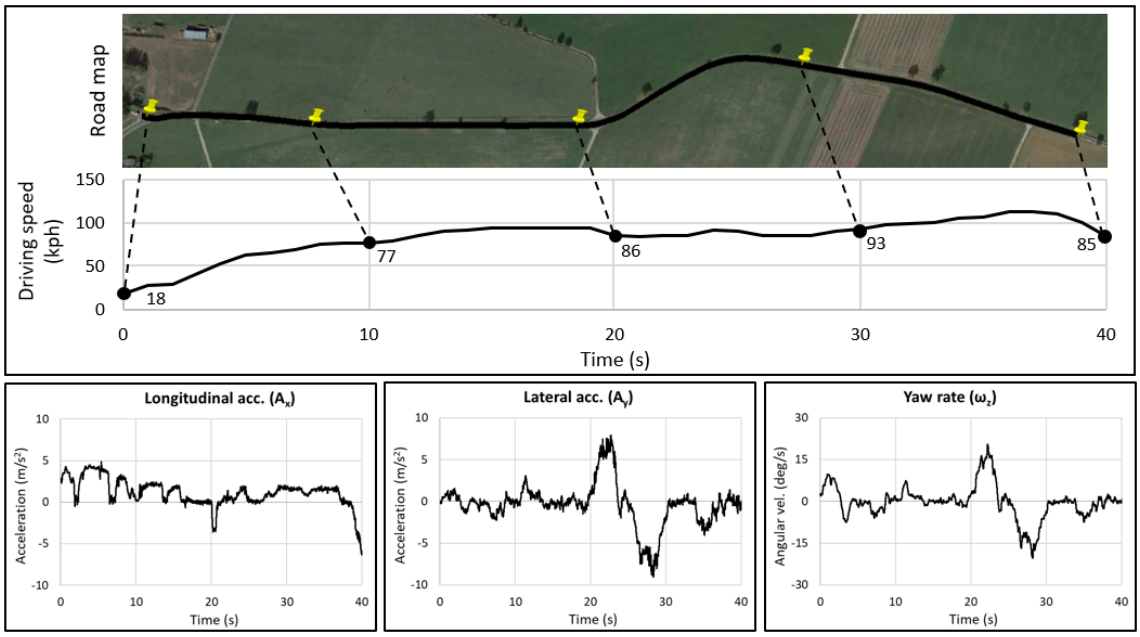

Fig. 2. Driving road map and measured vehicle kinematics.

Virtual Driving Testing

The steering angle profile during the test driving described in the previous section was reproduced with a 100Hz sampling rate by a virtual test-driving tool, CarMaker (IPG Automotive) as shown in Fig. 3. The visual road angles, which quantified the curvature of the driving road ahead from the driver's visual point of view was also manually gauged from an animated driving view at selected time intervals. The visual road angle was defined by the crossing angle between two tangential line-segments which were drawn along the far side of the road, Line A and the straight-ahead position, Line B (Fig. 3). The gauged visual road angles were +20° and -16 °, respectively ,for the bend to left (19-24 sec) and the bend to right (24-31 sec) road segments. The small size sedan model in the vehicle library of CarMaker was selected similar to the one used for the real test.

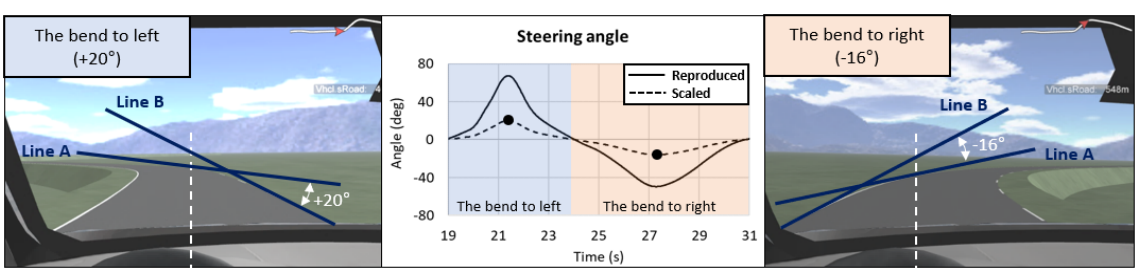

Fig. 3. Reproduced steering angle profile and visual road angles at bending road segments.

Virtual Simulation of Driver Kinematics

Active Human Body Model

The active human body model used for this study had the same modelling architecture for the spinal structure as the passenger model used for the prediction of kinematics at the evasive single lane change manoeuvre [2], which had four articulated joints, i.e., head/neck, neck/upper trunk, upper/centre trunks, centre/lower trunks. The reflexive muscle activation of a vehicle occupant was modelled by active joint

elements at each anatomical joint position. There were two basic elements at each joint, i.e., the passive kinematic joint element and the torque actuator. Vestibular reflexive muscle activation for the posture stabilisation was modelled by applying the active torques with PID closed-loop control. For simplification, the lower body of the human model was fixed to the rigid seat to which the vehicle motion was applied. More details of the active human body modelling can be found in [2].

Upper extremity modelling for steering action

The anatomical joint mechanism for the steering action by the upper extremity was implemented with two degrees of freedom (DOF) motions of the arm, i.e., flexion-extension and adduction-abduction at the shoulder joint, and another two DOF motions of forearm, i.e., flexion-extension and pronation-supination at the elbow joint. It was assumed that the steering action is produced only by the shoulder joint torque and thus the elbow joint was modelled as a passive joint. The three translational and on rotational DOFs of the hands were rigidly tied to the steering wheel at the 3-9 o'clock position but two other rotational DOFs were left free, which might compensate for the flexion-extension, radial-ulnar deviation motions at the wrist joint. Bilateral symmetry was applied to the modelling of the upper extremity.

Error Functions in PID closed-loop control

For active joint torque at the shoulder: Assuming the steering was rather a reflexive action to manoeuvre a vehicle along the driving path, the adequate joint torque at the shoulder needed to be generated to make the correspondent rotation of the steering wheel as the vehicle was turning. So, the error to be removed in PID control was the difference between the target steering angle profile (Fig. 3) and the current position.

For active joint torque at the head/neck complex: As mentioned in the introduction, the driver's head tilt was highly correlated to visual information than to the lateral centripetal force during the cornering. The steering angle profile in Fig. 3 was scaled such that the positive and negative peak values at the reverse curved road section (19-31 sec) matched with the corresponding visual road angles. This synthetic visual road angle profile was added to the PID error function which used to include only the segmental body angle.

The simulated head tilt was compared with the measured data as shown in Fig. 4. The measured head tilt profile was acquired retrospectively from the analysis of a video image. Two open-source face-tracking tools, #1: Google application programming interface (API) [4], #2: Face API [5] based on the machine learning algorithm were adopted and produced slightly different outcomes. (Fig. 4)

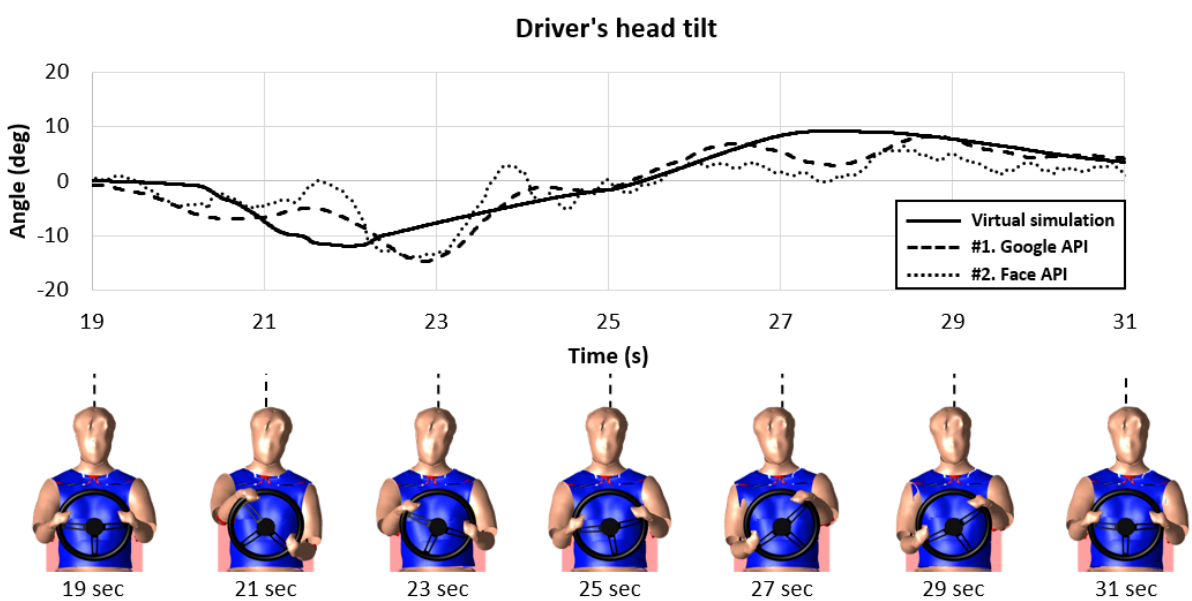

Fig. 4. Comparison of the driver's head tilt between test and virtual simulation.

III. INITIAL FINDINGS

The test results as vehicle kinematics, steering angle and visual road angle were successfully reproduced by the virtual test-driving tool with road and driving speed profiles (Fig. 2, 3).

For simulating the steering action of the driver, the active human body model which used to represent a passenger was updated by adding two DOF active motions at the shoulder joints and two DOF passive motions at the elbow joints. The steering action was driven by the active torque with PID control that minimised the error between target and current steering angles.

Keeping the known drivers' head tilt strategy [3] in view, the head tilt was produced by two joints at head and neck body segments with a PID control that also minimised the error between the current head tilt and the synthetic visual road angle profile. The simulated result of the head tilt showed a good and fair correlation against the measurement from the face tracking of the test video image (Fig.4). The simulated head tilt was quantitatively correlated against the test measurements by the CORA score (CORrelation and Analysis, v4.0.4) [6]. The CORA scores with the ISO9790 Biofidelity rating were 0.750 (rating for *good*) and 0.503 (*fair*), respectively, against face tracking #1 (Goggle API) and #2 (Face API). Meanwhile, the CORA score between face tracking #1 and #2 was 0.711 (*good*).

IV. DISCUSSION

Limitations of this study

In the virtual driving test, road roughness and altitude change were not included. In the actual road profile, there is altitude change from -4 m to +2 m.

In the virtual simulation of driver kinematics, assumed no resistance for steering wheeling. And there is no interaction with the human body model because the rigid seat was used. So, the lower extremity was fixed and only head tilt was analysed, i.e., no comparisons of head displacement, trunk angle, etc. Finally, there is a correlation against just one test subject data. In other words, there are no inter-subject and intra-subject variations.

The computation aspect of the virtual simulation

The real-time factor (ratio of a centre processing unit (CPU) and physical times, 424sec/45sec) was 9.4 at intel I7-9700 3.6GHz, 16 GB random access memory (RAM). And current modelling features to affect positively CPU time is the removal of computer-aided design (CAD) data, i.e., skin shape, deactivation of the surplus output data, processing after compiling and building, i.e., .exe file, modularization of active torque calculation. The next-term modelling features to affect negatively on CPU time is deformable seat and belt, activation of joint DOF at the lower extremity, including pedal operation.

V. REFERENCES

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