An Experimental Framework of Capturing Driver's Pre-Crash Active Behaviour under Safety-critical Scenarios

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I. INTRODUCTION

Drivers' pre-crash behaviours, such as posture and physiological states, significantly affect the subsequent injury risk in the crash phase [1-2]. In contrast to the in-vehicle test and the sled test, the driving simulator can reconstruct safety-critical scenarios from the real world as closely as possible while ensuring volunteer safety and measuring driver response subject to simulated road traffic hazards. The present study proposes an experimental framework for extracting the driver's active response from hazard appearance to the simulated occurrence of vehicle collisions. During the reaction process, and under different urgency levels, the driver's posture changes and surface electromyography (EMG) signals are recorded in real-time.

II. METHODS

The experimental platform mainly consists of a 6-DOF driving simulator, motion-capture system, EMG device, depth cameras, and RGB colour cameras (Fig. 1). Synchronization among devices is realized through ZeroMQ communication based on C++. The car's following behaviour is designed to reproduce the safety-critical scenario, starting from the driver stimulated by a pre-defined hazard to collision occurrence [3]. Four independent variables are used to measure the urgency level: the emergency braking deceleration of the leading vehicle (LV); the initial headway time; whether the brake lights of LV work or not; whether there are other vehicles in the side lane.

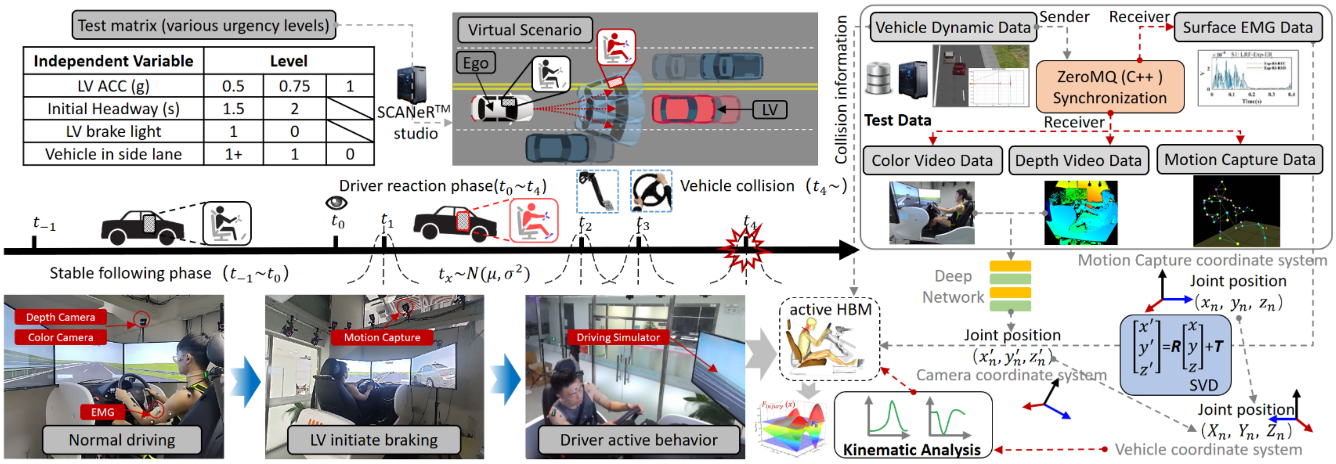

Fig. 1. An experimental framework for capturing drivers' active behaviours in safety-critical scenarios.

A total of 24 male volunteers (37.6±6.0 years, 175.5±4.6 cm, 78.7±10.4 kg) with professional driving skills (driving experience ≥ 5 years, annual mileage ≥ 10,000 km) participated in the experiments. The experimental procedures were approved by the Institutional Review Board (IRB) of Tsinghua University. The volunteers were given about an hour to drive in different scenarios and familiarize themselves with the basic operations of the driving simulator, including emergency braking, steering, etc. Then, the volunteers were asked to drive an automatic transmission car simulator with a standard seat belt and to follow the LV steadily at 120 km/h on the inner lane of a two-lane freeway. When the driver's following headway met the design condition and maintained a random 5–10 s, the LV would brake suddenly. For each scenario, three repeated trials were performed (12 urgency levels × 3 repeated trials × 24 volunteers = 864 cases). In addition, we randomly interspersed scenarios

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where the LV does not brake and used a pseudo-randomization to balance the order of presentation of the trials so that learning effects could be reduced [4]. The kinematic data of different coordinate systems are transformed by translation matrix and rotation matrix (calculated by Singular Value Decomposition, SVD).

III. INITIAL FINDINGS

Drivers (volunteers) complete the process of releasing the throttle (t_1 means fully releasing) and stepping on the brake (t_2 means initial brake onset, t_{2max} means braking to maximum) when perceiving the hazard, starting from LV braking (t_0 = 0 s). Then, the driver decides whether to steer (t_3 means beginning steer) or not, depending on his driving style. For high urgency level scenarios (e.g. LV deceleration = 1 g, initial headway < 1.5 s, LV brake lights fail, without vehicles in the side lane), there is a significant difference (paired t-test, $p < 0.05$) in the resulting average T1 forward displacement (T1-X), lateral displacement (T1-Y), and three projected rotation angles of the trunk (Rotation, Lateral tilt, Inclination, Fig. 2) between any two reaction times (t_1, t_2, t_{2max}, t_3).

In scenarios with different urgency levels, the timing when three projected rotation angles of the trunk reach the maximum value lies between t_2 and t_3 (between the red dotted line and blue dotted line in Fig. 2). As a preliminary analysis, we performed K-means clustering on the relative trunk angle at t = 2 s of all cases, setting the class of clusters to 5 according to the driver's behaviour characteristics [1]. Consequently, the active behaviours were categorized into: (1) *backward trunk lean* (14%); (2) *trunk lean and twist* (9%); (3) *forward trunk lean slightly* (22%); (4) *forward trunk lean obviously* (16%); (5) *normal driving posture* (39%). The EMG amplitudes of left lumbar paravertebral muscles (LPMl), left rectus abdominis (RAl), right rectus abdominis (RAr) in the backward leaning posture are significantly different (two-sample t-test, p < 0.01) from those in the forward leaning posture, while the right lumbar paravertebral muscles (LPMr) exhibit no significant difference.

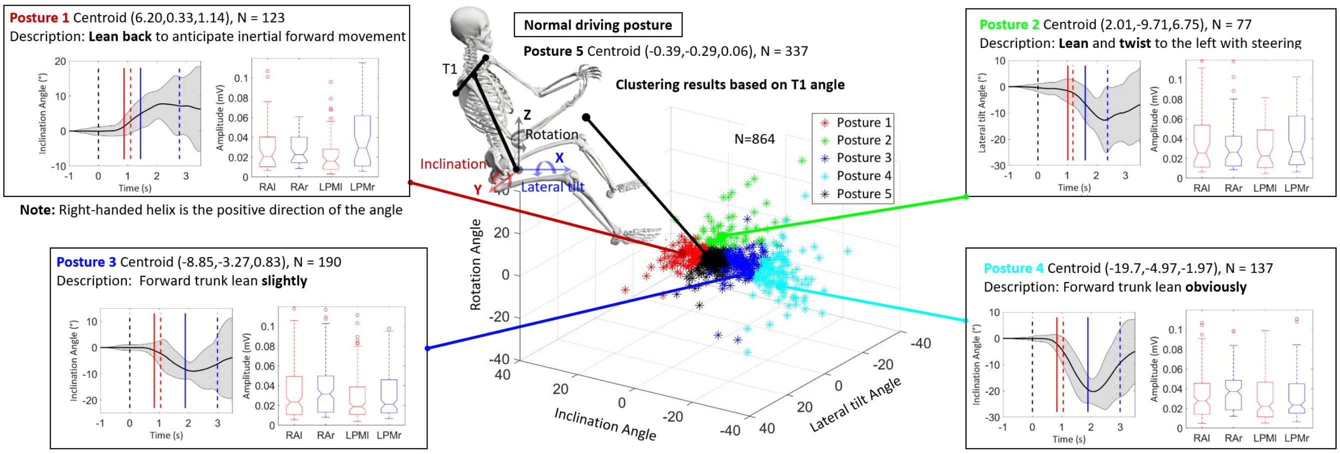

Fig. 2. Clustering results of drivers' active behaviour in safety-critical scenarios. Trunk kinematics data are presented as corridors of average responses ± one standard deviation. The vertical red, red dotted, blue and blue dotted lines indicate the average timing of t_1, t_2, t_{2max}, t_3. The EMG amplitude analysis of different clusters is shown on the corridor figures' right side.

IV. DISCUSSION

We quantified drivers' active behaviour, including the posture (kinetic point of view) and EMG, during pre-crash in safety-critical scenarios. Such pre-crash active behaviour exerts a highly nonlinear influence on vehicle dynamics, as reflected in the driving simulator, and probably on the subsequent injury severity if a collision occurs. For example, the driver would lean and twist to the left during steering (Posture 2, Fig. 2), making himself deviate from a normal driving posture and thus affecting the seat-belt's protective performance in an unavoidable collision. These results serve an accurate description and provide a data reference for safety risk investigation, development of biofidelic models, and restraint design. Quantification of active behaviour of female drivers and higher-dimensional clustering considering the kinematics of other body regions (e.g. the head) will be examined in our subsequent studies.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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