Constructing a virtual testing platform on pedestrian safety incorporating active human behaviour for highly automated vehicles

Siyuan Liu, Quan Li, Qing Zhou, Bingbing Nie*

I. INTRODUCTION

Pedestrians face high injury risks in road traffic accidents involving collisions with motor vehicles. Humans' natural reaction ("active behaviour") in emergency traffic situations largely influences the occurrence and severity of the subsequent accident. A quantitative description of active behaviour features, as reported in recent studies [1], can be used in testing the protection performance of integrated pedestrian safety systems, especially for highly automated vehicles (HAVs). For this purpose, this study proposes a virtual testing platform on pedestrian safety, incorporating active behaviour, involving reconstructed, representative collision scenarios.

II. METHODS

The framework of virtually reconstructing representative vehicle-pedestrian collision scenarios is illustrated in Fig. 1. For each tested HAV, we defined interaction with an "active" pedestrian who exhibits natural hazard perception, recognition and avoidance kinematics. The subsequent collision risk is identified and considered for on-vehicle safety systems. Data on pedestrians' active behaviour were previously collected via virtual reality (VR)-based experimental collision scenarios [1]. We further determined the distribution of kinematics according to different age groups, i.e. young (20–40 years), middle-aged (40–60 years) and senior (60–80 years).

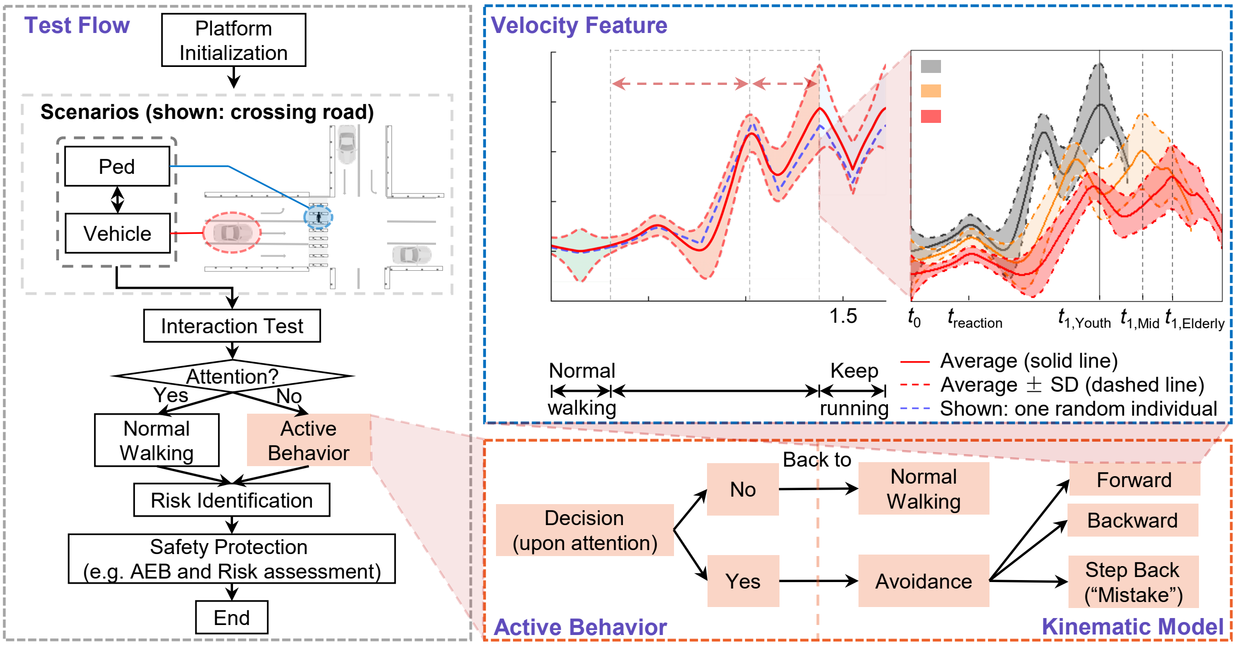

Fig. 1. The testing platform incorporating pedestrians' active behaviour in the collision (shown in detail: typical velocity feature of the youth's forward kinematics model; age feature of different groups during avoidance).

Running logic of the virtual testing platform

Virtual pedestrians in a normal walking state are generated in front of the vehicle to start one round of testing. First, the HAV judges whether the pedestrian has a collision risk based on the distance-based safety envelope [2]. Second, when the pedestrian's position relative to the vehicle violates the safety boundary, one individual virtual pedestrian is activated with a selected avoidance scheme (see next subsection). Then, based on the active behaviours of pedestrians, the vehicle identifies the collision risk and starts protective measures, such as braking and pedestrian airbags (when the collision is unavoidable).

The natural behaviour of a virtual pedestrian and the age distribution

During the vehicle-pedestrian interaction in a collision scenario, pedestrian kinematics is divided into three stages: normal walking (0-t_0); active responses (t_0-t_1); and keep moving (Fig. 1). The active pedestrian behaviours are categorised into four schemes: (1) backward avoidance; (2) forward avoidance; (3) oblique stepping

B. Nie (e-mail: nbb@tsinghua.edu.cn; tel: +86-10-6278-8689) is an Associate Professor, S. Liu is a PhD student, Q. Li is a Research Associate, Q. Zhou is a Professor, all in the School of Vehicle and Mobility at Tsinghua University and State Key Laboratory of Intelligent Green Vehicle and Mobility, China.

("mistake" decision); and (4) normal walking (no attention to the hazard) [1]. The natural avoidance velocity is divided into two gaits based on gait analysis, e.g. gait 1 and gait 2 in the velocity feature. Then, five kinematic parameters are selected to define a piecewise kinematic equation representing each gait's velocity feature.

We designed a mapping relationship of the kinematic equations from young pedestrians (22.2±1.8 years) to middle-aged and senior pedestrians, i.e. the functions on the age distribution of physiological and kinematic parameters of the human body (e.g. hip flexor and abductors muscle strength [3]). We calibrated the mapping results using the normal walking speed curve of an 80-year-old male (reported in [4]).

III. INITIAL FINDINGS

We virtually constructed typical vehicle-pedestrian collision scenarios, including intersections and T-junctions (interface designed using MATLAB 2021). During the test, we defined the "safety envelopes" to identify the safe (collision avoidable) and hazardous (collision unavoidable) zones between the vehicle and the pedestrian (Fig. 2). The perception capability of the pedestrian and the HAV further distinguishes the interaction scenarios. For example, when the pedestrian and the vehicle notice each other, pedestrians move with avoidance behaviors, while the vehicle takes proper safe control. With a particular focus on human behaviour, we noticed that pedestrians who take active avoidance have a smaller hazard zone, regardless of the age group. Middle-aged and senior pedestrians have larger hazard zones than young adults, possibly due to muscle aging.

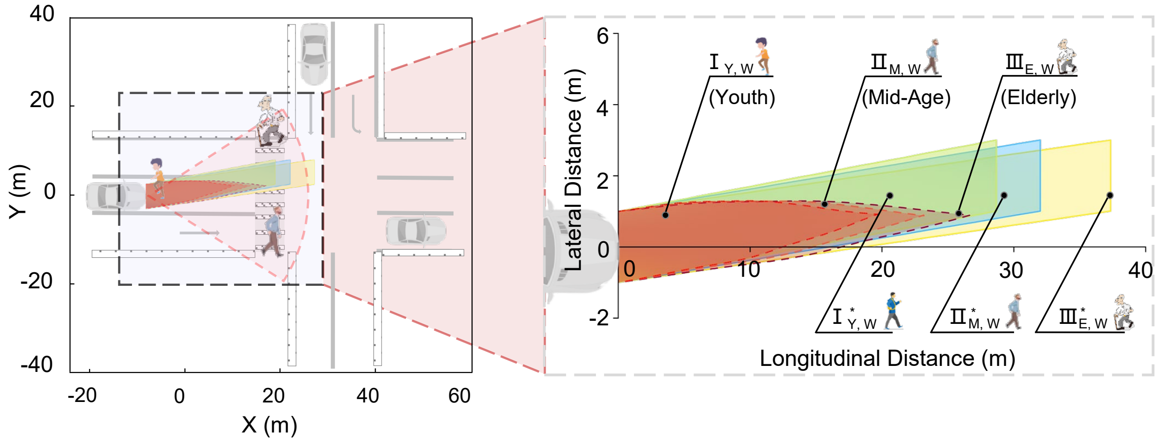

Fig. 2. Visual interface of the testing platform (shown in detail: the coloured hazard zones indicate the initial pedestrian locations with collision risk; * represents normal walking with no active avoidance).

IV. DISCUSSION

Active behaviour prediction of the pedestrian has the potential to reduce the collision risk or injury severity, especially for HAVs with rich sensing information ahead [5-6]. Furthermore, considering pedestrian avoidance behaviour can improve driver acceptance in complex scenarios with many pedestrians and high traffic, where drivers usually get annoyed by their cars stopping for no apparent reason. Yet, the numerical models for active safety systems have seldom considered pedestrians' reactions. With the widespread use of modeling, we anticipate that biofidelic human models (such as those with active responses) can provide efficient tools for optimal protection. As more interactions occur between humans and HAVs on roads, such efforts will extend the classic modeling of impact injury to further include the active behaviour of a human in real-world traffic scenarios.

Humans' cognition capability and muscle state change significantly with aging. However, the behaviour data for the senior group is limited due to the experimental ethics involved. Therefore, we built the mapping model using accumulated experimental data and gait analysis. With a view to the test applications, the mapping avoidance equation is calibrated based on the normal walking data of the senior group. With the proposed scaling factor, the calibration data provided an upper limit constraint for the mapping data. Nonetheless, as a preliminary investigation, this study only did a superficial check for the validity of the mapping results and ignored the mechanism of pedestrians' decision-making and cognition changes with aging. Furthermore, the population groups were restricted to adults; children, with their immature cognition of the potential collision hazard, would require tailored protection in the vehicle safety systems.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] Li, Q., *et al.*, *IRCOBI* Aisa, 2020.
[2] Nie, B., *et al.*, *SCI Rep*, 2021.
[3] Pasco, J. A., *et al.*, *BMC Musculoskel Dis*, 2020.
[4] Kavanagh, J. J., *et al.*, *HUM Movement Sci*, 2005.
[5] Wang, S., *et al.*, IV, 2021.
[6] Eiffert, S., *et al.*, *IEEE Robot Autom Let*, 2020.