Towards Systematic Finite Element Accident Reconstructions involving Vulnerable Road Users

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I. INTRODUCTION

Last year, the World Health Organization (WHO) reported that more than half of the 1.19 million road traffic fatalities in the world occurred among vulnerable road users (VRUs) [1]. Many of these fatalities were due to sustained head injuries, which remains one of the leading causes of death and disability among victims of road traffic accidents [2]. Typical head injuries include extra-axial haemorrhages caused by ruptured veins and arteries, diffuse axonal injuries, concussions or different types of skull fracture. Understanding the mechanisms behind these head injuries is crucial to enable the development of preventive measures [3]. Computational Finite Element (FE) models have emerged as powerful tools for unraveling the intricacies of traumatic head injuries. By studying the impact response in terms of e.g. stresses and strains, anatomically detailed virtual human surrogates, in combination with realistic material models, can provide deep insight into the injury mechanisms of specific tissues during dynamic loading scenarios. By reconstructing real-world accidents, the biomechanical response of the human body can be predicted and can contribute to characterising the injury mechanisms in conditions under which individuals are injured [4].

Accurate prediction and analysis of head injuries require complex models and methodologies that can replicate real-world scenarios with a high degree of fidelity. In this study, a method for reconstructing VRU-to-vehicle traffic accidents will be proposed to outline a step-by-step reconstruction methodology. The methodology will compile methods for Human Body Model (HBM) personalisation, HBM positioning, vehicle personalisation, and set-up of simulation boundary conditions (BCs).

II. METHODS

To perform a detailed reconstruction of a VRU-to-vehicle collision, representative FE models needs to be prepared for (1) the pedestrian/bicyclists and (2) the impacting vehicle(s), and (3) one needs to determine the boundary conditions of the case that will be reconstructed. These crucial steps in the current reconstruction methodology are presented below. To exemplify the reconstruction pipeline and to illustrate the potential use of the reconstructions, 20 real-world accidents were reconstructed.

(1) Case-specific HBMs

The importance of including females and wider size ranges in traffic safety assessments is being recognised more and more [5][8]. In this pipeline, the BMI and sex of the subjects were accounted for by following a mesh morphing technique [5]. The technique is based on image registration, where the HBM is morphed to a certain target geometry generated from skinned vertex-based body shapes and skeletons (see SMPL, SMPL-X and OSSO [6-7]). Positioning was carried out by simulations using pulling cables (marionette method) [8]. The mass of the subject was tuned by scaling the fat tissue density. This pipeline is compatible with several available HBMs [5], although here, the SAFER HBM v10 pedestrian [8] was used.

(2) Vehicle models

It has previously been asserted that the vehicle geometry (e.g. bonnet leading edge, front height [9-10]) is a major influence on the pedestrian kinematics. Thus, the vehicle model was modified for each reconstruction case to achieve a better representation of the real-world impacting vehicle geometry. Three different vehicle models were used in this study. For the simplest cases, where the subject impacted the centre of the vehicle and did not strike any complex car structures such as the A-pillar, a generic sedan buck model was used [11]. The modular

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components of the buck were translated and/or rotated to match the impacting car side-profile geometry for each case following a semi-automatic pipeline [12]. For more complex impacts, open source models of a sedan car or SUV were used [13]. These models were originally developed for crash testing and thus have a high degree of detail in comparison to the generic buck model, but at greater computational expense. The side-profile geometry of the sedan/SUV was modified for each case using a morph volume approach. The same frangible windshield model was implemented for all used vehicle models [14].

(3) Boundary conditions

The height of the car relative to the ground was determined by processing of vehicle photographs [12]. The velocity of the cars was obtained by China Automotive Technology and Research Center (CATARC) from video analysis or the car's event data recorder. The position of the HBM relative to the vehicle was determined based on the video material.

III. INITIAL FINDINGS

Real-world accident cases were chosen from the China In-Depth Accident Study (CIDAS) database, which compiles thoroughly documented and analysed traffic accidents collected by CATARC. The selected cases comprised road traffic accidents where an adult pedestrian or bicyclist collided with a car, the accident was documented with moving images (CCTV and/or dash cam), and the head injury type was documented in detail or the lack of head injury was confirmed. Twenty real-world cases were successfully reconstructed following the suggested pipeline. The validity of the cases was mainly assessed based on the qualitative comparison of the video and the simulation animation, and of the simulated and recorded vehicle deformation. The on-scene measured Wrap Around Distance (WAD) was compared with the simulated WAD. In general, the striking similarities between the surveillance footage and simulation predictions, as well as the predicted and documented vehicle deformations, increase the confidence in using this reconstruction approach (see an illustrative example in Fig. 1). The results emphasise how CCTV and dash-cam recordings work as a powerful tool of validation and accuracy assurance.

IV. DISCUSSION

In this study, we have attempted to outline a methodology for systematic reconstruction of real-world VRU-to-vehicle recorded accidents. With increasing amounts of traffic accident databases and available accident data, a robust and accurate reconstruction methodology is of high importance to draw trustworthy inferences and to develop injury risk curves and thresholds. This study emphasises how video recordings of traffic accidents significantly increase the credibility of and trust in the reconstructions. As this work prolongs, the documented injuries will be matched with the predicted ones and subsequently, head injury mechanisms in these accidents will be studied.

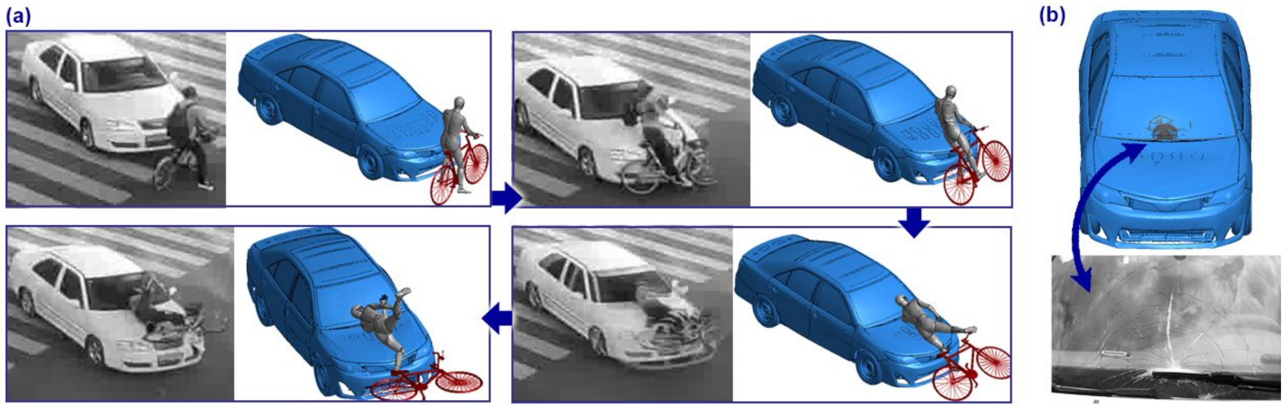

Fig. 1. (a) Snapshots from selected time steps of a reconstructed bicycle accident comparing the CCTV material with the simulation model. (b) The predicted damage to the car of the same case as (a) compared to on-scene photographs of the impacting vehicle.

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