Crash Reconstruction Based on 3D Image Techniques, Multi-Rigid-Body Reconstruction and Optimised Genetic Algorithm

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I. INTRODUCTION

In China, the national statistic authority reports about 100,000 traffic fatalities each year, and the traffic police have to identify the driver responsibility for each accident. Traditionally, the analysis of the course of a traffic accident depends on the experience of forensic experts. Recently, multi-body system (MBS) simulations are becoming a popular modeling method for real-world crash reconstruction and injury evaluation. However, the use of the multi-rigid-body dynamic method depends on accurate accident data, including impact position, braking distance, driving speed, etc. The more detailed the data are, the more realistic the simulation results will be. Besides, a limited number of simulations typically involves subjective evaluations of pre-impact parameters.

In this study, we present a multi-mode image system consisting of unmanned aerial vehicle (UAV) photogrammetry, 3D laser scanning and structured-light scanning to obtain accurate information of roadway, vehicle and pedestrian. Then the genetic algorithm (GA) was applied to optimise uncertain pre-impact parameters based on MBS simulations. A real case was analysed to verify the feasibility and effectiveness of the system.

II. METHODS

Case Description

Data required for accident were provided by the Academy of Forensic Science in Shanghai including detailed documents about police investigations, witness testimonies, litigant statements and a video record. The post-mortem examination and vehicle inspection were performed by the Academy of Forensic Science. The accident can be summarized as follows. A 66-year-old male pedestrian was struck by a Volkswagen Golf vehicle when he pushed his tricycle across the road. The windshield was radially cracked, with the victim’s hair in the centre (Fig.1). There were paint scuffs and an impact fracture on the right side of the front bumper, which corresponded to the damage found on the left side of the tricycle. Further evidence of contact was depressed deformations at the region of licence plate and bonnet front., and there was bruise on the victim’s left iliac region.

Fig.1 a. Volkswagen Golf involved in this accident; b. impact fracture at the left side of the tricycle; c. the bruise on the victim’s left iliac region; d. laceration and contusion around the left eye and the left frontal.

Documentation of the Accident Scene

The documentation of the accident scene was conducted using a commercial DJI MAVIC PRO (DJI, CHINA). The documentation area and flight route were formulated by Pix4D capture software and approximately 300 images were captured at the scene. We further processed those images with Contextcapture4.0 software to generate 3D textured digital model.

Documentation of Vehicle and Tricycle

For the 3D documentation of the vehicle and tricycle, Faro Focus 3D S120 (Faro, USA) laser scanner was utilised with a range accuracy of 2 mm. The laser scanner sends laser beams while rotating with a horizontal angle of up to 360°and a vertical angle of up to 310°. Four scans for the vehicle and three scans for the tricycle from different locations were performed to improve accuracy and eliminate shadows. Those point clouds were stitched together by using the known locations of ground control points (GCPs) or other features within the scene. A 3D model of the vehicle was created out of the point cloud using Scene 2019 software.

Documentation of the External Findings of the Body

We performed whole-body scanning by GO!SCAN 50 (Creaform, Canada) with a resolution of 1mm during the autopsy. These hand-held structured light scanners enable users to observe the state of the scanned model in real-time by connecting to a laptop and to augment any lacking areas with additional scanning. A true to scale and high-resolution model was created as the scanner moved over the decreased.

Estimate pre-impact speed of the vehicle

We played the video using Smart Player and selected 8 frames (Figure 2). There are 16 frames per second in the video. We used the two edges of the intersection as reference lines. As Figure2 showed, the involved vehicle was close to reference line A at first frame and reached reference line B at 9th frame. The distance between the reference lines was 9.58m, which was measured by the 3D model of the accident scene. The velocity was calculated by the following formula.

$$v = \frac{l}{t} \approx \frac{9.58}{(9-1) \times \frac{1}{16}} \approx 19.16 m/s$$

This velocity was a preliminary estimate value. Therefore, we set the range of velocity variable at [15m/s,25m/s].

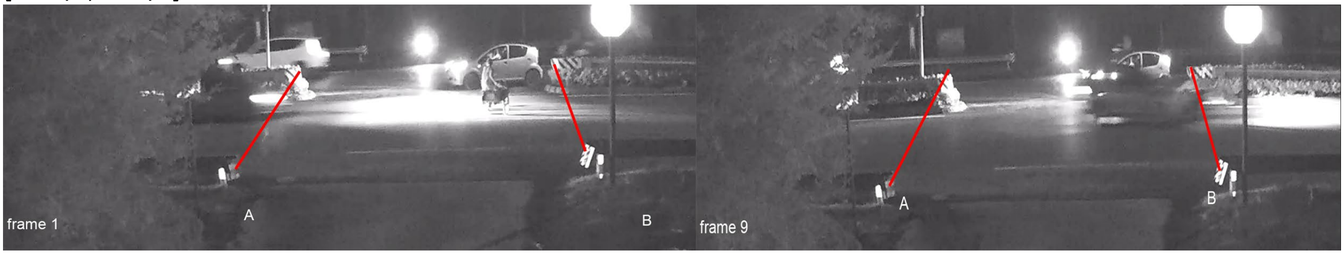

Fig.2. The screenshot of surveillance video beside the road

Modeling

According to the accurate measurement by laser scanning, a detailed facet type multi-body of the vehicle was developed in MADYMO. According to the accident data provided by police, the model of vehicle is Volkswagen FV7144LBDBG. We chose a similar car which had been tested in EuroNCAP. It can be used to apply the red, green and yellow curves obtained by Martinez's paper in the red, green and yellow rated areas on the car. The force-deflection curves were illustrated in Figure 3 [1]. Similarly, the multi-rigid body model of the tricycle was established [2-3], including the frame, front and rear wheels, handlebars and pedals. The MADYMO 50th percentile male model was chosen as reference dummy and then scaled according to height and weight of the victim.

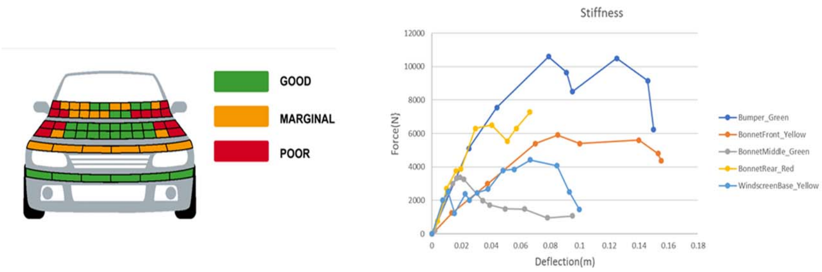

Fig.3. representation of force-deflection curves for vehicle model

Optimsation Method

Optimisation was conducted to find out the best values for uncertain parameters, such as vehicle speed, impact angle, etc, to match the simulation kinematic response with known kinematics. There were three pairs of matching points in this accident (Fig.2). A contact marker was attached to the centre of the spiderweb fracture pattern on the windshield, which was assumed to be the primary contact of the human head. By computer-assisted 3D comparison of highly precise, true-colour 3D surface digitizing of the external findings and the involved vehicles (Figure.6), we can believe that the injury of iliac region was caused by the corresponding damaged regions of the vehicle bonnet front. The last pair of markers was located at the right side of the front bumper and the left side of the tricycle. The objective function was to minimise the weighted sum of the minimum distance of related markers. The optimisation variables include the vehicle speed, impact angle of the vehicle (α) and the axial rotation of the pedestrian (β) and tricycle (γ) around the vertical axis. The range of the design variables was estimated based on video data (Table1). According to the video data, the pedestrian pre-impact motion was neglected in this accident. We chose the non-dominated sorting genetic algorithm-II (NSGA-II) to complete the optimisation. Twenty generations were performed in an optimisation with 12 designs in each generation, resulting in 240 simulations in total. The computation time lasted approximately 30 h for all simulations.

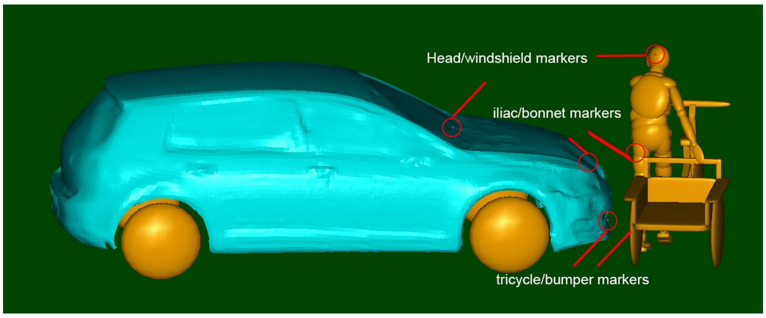

Fig.4. Contact markers of the victim, tricycle and vehicle model used for defining the objective function.

TABLE 1 RANGE OF OPTIMISATION VARIABLES

Optimisation parameters	Minimum	Maximum
v(m/s)	15	25
α(rad)	-0.5	0.5
β(rad)	-0.5	0
γ(rad)	-0.5	0

III. INITIAL FINDINGS

Crash Reconstruction Results

The complete model of the accident scene, vehicle, tricycle and the external body of the deceased are shown in Fig.5. Traces of the scenario, vehicle deformation and injuries of the victim are true to colour and scale, enabled the transfer of the virtual body into the virtual incident scene. However, the documentation of the vehicle is not ideal for the windscreen, headlights and other structures where the laser reflection was affected.

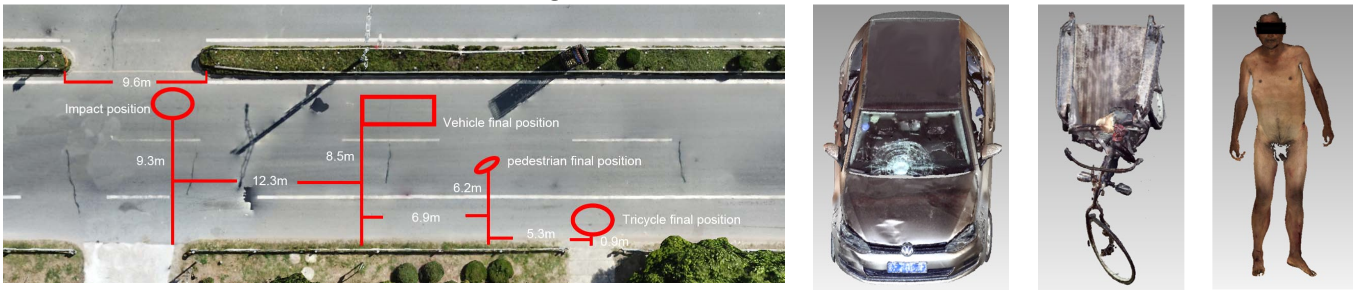

Fig.5. 3D documentation of the incident scene, vehicle, tricycle and body of the victim.

Fig.6. 3D comparison of the external findings and the involved vehicles

Optimisation Results

After 240 simulations, the most closely matched result was acquired in the 12thgeneration. The dispersion of the design points tested by the NSGA-II method was significantly decreased during the iterative process (Fig.7), suggesting a fast convergence in the crash reconstruction problem.

The Most Closely Matched Results

The sum of the objective function was 0.032754m. The vehicle speed (v) was set at 19.08 m/s and the impact angle (α) was -0.0349 rad. The axial rotation of the pedestrian (β) and tricycle (γ) around the vertical axis were −0.212 rad and -0.186 rad. The left iliac region had a full contact with the marked bonnet front region, and then the body began to slide over the hood, and finally the victim's head stroke the windshield. The condition at the time of head–windshield impact is illustrated in Fig.8. The HIC15 score of the human model was 7083.8 and thorax 3ms acceleration was 444.63m/s2. The HIC score is corresponding to fatal head injury, which correlates well with the actual skull fracture and subarachnoid hemorrhage. Thorax 3ms acceleration is lower than 60g, which indicates that the relationship between death and thoracic injuries is not certain. This is consistent with a lesser thoracic injury.

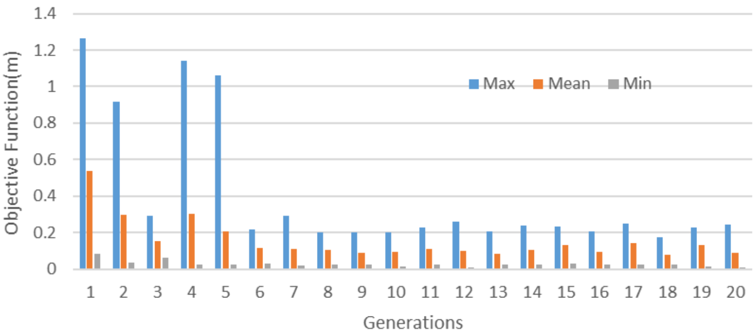

Fig.7. Objective function for every simulation during the NSGA-II process.

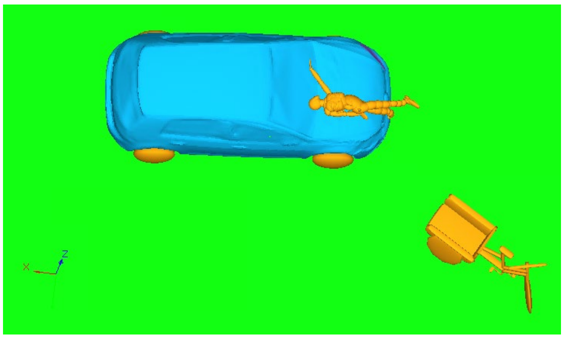

Fig.8 Crash reconstruction result at the time of head-windshield impact (t=85ms).

IV. DISCUSSION

In the present study, an improved system combined with 3D image techniques, MBS, and optimised algorithm was developed for accident reconstruction. The three-dimensional documentation of the vehicle, body and incident scene saves permanent and raw material for the crash. Furthermore, it is an effective way to provide accurate measurements and to verify different hypotheses. Compared with a multi-body model, the facet model based on result of laser scanning has a more precise shape for simulation. Meanwhile, this study shows that the NSGA-II algorithm has the capability to find solutions in the close vicinity of the exact solution and exhibits fast convergence.

However, there are some limitations in this preliminary study. First, the UAV is not suitable for operation in the evening and on rainy days. There are also some data missing for the structure of glass material when it comes to laser scanning. Second, the stiffness of the vehicle and tricycle was obtained from an impactor test for a similar vehicle in the previous literature. The friction coefficients were also adjusted according to the literature. Third, the population size and the number of designs per generation in this study were refer to previous experiences, future work should consider further improvements of the optimal parameters and variables. Finally, a combined application of the multi-body and finite element methods is needed for further injury mechanism research. More accident cases are needed to verify the accuracy of the system in the future.

V. REFERENCES

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