Journal of Safety Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

# Automated recognition of rear seat occupants' head position using Kinect™ 3D point cloud

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A R T I C L E  I N F O

*Article history:*
Received 27 January 2017
Received in revised form 18 September 2017
Accepted 9 October 2017
Available online xxxx

*Keywords:*
Child occupant protection
Naturalistic driving study
3D mapping
Microsoft Kinect
Point cloud

A B S T R A C T

*Introduction:* Child occupant safety in motor-vehicle crashes is evaluated using Anthropomorphic Test Devices (ATD) seated in optimal positions. However, child occupants often assume suboptimal positions during real-world driving trips. Head impact to the seat back has been identified as one important injury causation scenario for seat belt restrained, head-injured children (Bohman et al., 2011). There is therefore a need to understand the interaction of children with the Child Restraint System to optimize protection. *Method:* Naturalistic driving studies (NDS) will improve understanding of out-of-position (OOP) trends. To quantify OOP positions, an NDS was conducted. Families used a study vehicle for two weeks during their everyday driving trips. The positions of 41 rear-seated child occupants, representing 22 families, were evaluated. The study vehicle – instrumented with data acquisition systems, including Microsoft Kinect™ V1 – recorded rear seat occupants in 1120 driving trips. Three novel analytical methods were used to analyze data. To assess skeletal tracking accuracy, analysts recorded occurrences where Kinect™ exhibited invalid head recognition among a randomly-selected subset (81 trips). Errors included incorrect target detection (e.g., vehicle headrest) or environmental interference (e.g., sunlight). When head data was present, Kinect™ was correct 41% of the time; two other algorithms – filtering for extreme motion, and background subtraction/head-based depth detection are described in this paper and preliminary results are presented. Accuracy estimates were not possible because of their experimental nature and the difficulty to use a ground truth for this large database. This NDS tested methods to quantify the frequency and magnitude of head positions for rear-seated child occupants utilizing Kinect™ motion-tracking. *Results:* This study's results informed recent ATD sled tests that replicated observed positions (most common and most extreme), and assessed the validity of child occupant protection on these typical CRS uses.





## 1. Introduction

Vehicle occupants, and child occupants in particular, constantly move, sleep, or play in the rear seat of vehicles. Previous research has found that child occupants often move from the optimal position prescribed for the efficient functioning of their restraint system throughout the duration of the driving trip (Charlton, Koppel, Kopinathan, & Taranto, 2010; Forman, Segui-Gomez, Ash, & Lopez-Valdes, 2011; van Rooij, Harkema, de Lange, de Jager, Bosch-Rekveldt, & Mooi, 2005). These behaviors may not only impact the effectiveness of the restraint system, but may negatively influence the driver's attention and performance (Koppel, Charlton, Kopinathan, & Taranto, 2011). Quantification of the diversity and frequency of children's positions and out-of-position (OOP) statuses can inform the design of new test programs with Anthropomorphic Test Devices (ATD) that will more closely mimic human vehicle occupants. These new tests will facilitate a paradigm shift in the advancement of child occupant protection, away from safety technology designed to protect an ideally positioned occupant, and toward dynamic restraint systems that maintain optimal restraint over a range of expected occupant positions and movements in a vehicle, during real-world, everyday driving trips. (See Table 1.)

Naturalistic driving studies (NDS) represent an increasingly useful and sought after resource for understanding real-world behaviors in motor vehicles, including children's OOP trends (Dozza, Bärgman, & Lee, 2013). However, these studies also present difficulties for analysis, as they generate huge quantities of highly heterogeneous data that challenge 'conventional' analytical protocol (Dozza et al., 2013). As a result, exploring novel methods of analysis is critical to realizing the full potential of NDS.

Hence, in order to better understand the diversity and frequency of suboptimal positioning by rear seat occupants, an NDS was undertaken through a multi-disciplinary collaboration of engineers and behavioral scientists in Australia, the United States, and Europe to quantify the differences between optimal and actual posture and position of child occupants in the rear seat (Charlton et al., 2013). For this study, which

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https://doi.org/10.1016/j.jsr.2017.10.005
0022-4375/© 2017 Published by Elsevier Ltd.

**Table 1**
Reasons for native algorithm incorrect recognition.

| | |
|---|---|
| Incorrect target | Child restraint system (CRS) structure |
| | Another car part |
| | Occupants' body, other than the head |
| | Clothing |
| Technical error | Noise in image due to sunlight |
| | Dark image due to unidentified reasons |
| Occlusion | Scene blocked by front seat passengers or belongings of occupants |

took place in Melbourne, Australia from August 2013 to October 2014, two study vehicles were instrumented with video cameras and data acquisition systems. Additionally, one of the vehicles was instrumented with a Microsoft Kinect™ system V1, composed of an RGB camera and depth sensors to provide 3D motion capture of rear seat occupants. The study vehicles were loaned to families with young children for a two-week data collection period for naturalistic observation of rear seat occupant behavior during their normal, everyday driving trips.

Another paper, published in 2016 in *Traffic Injury Prevention* (Arbogast et al., 2016), details one method of data analysis utilized for this NDS, as well as that method's preliminary results. This paper provides a detailed account of the study's data collection methodology, as well as three other novel methods of algorithmic assessment for processing the Microsoft Kinect™ data. These algorithms will contribute to the repertoire of analytical methods available to researchers in the future, particularly as NDS increases in prevalence and incorporates new data acquisition systems.

## 2. Methods

### *2.1. Vehicle instrumentation*

Two study vehicles – a 2006 Holden Statesman and a 2007 Holden Calais – were instrumented for the NDS. Both study vehicles were instrumented with a dedicated vehicle-based data acquisition system, as well as a set of conventional video cameras.

#### *2.1.1. Data acquisition system*

Two GPS-enabled VBOX™ (Racelogic Ltd., Buckingham, UK) data acquisition systems were installed in each study vehicle (stored in the trunk) to provide vehicle position data and information on vehicle speed, acceleration, and braking.

#### *2.1.2. Conventional video cameras*

The conventional video system was comprised of eight cameras located in the vehicle interior, strategically positioned to gain an overall view of the forward road scene and the interior of the cabin, with minimal disruption to the driver's view and maximum concealment from vehicle occupants. The cameras provided views of the child occupants (both front and lateral views) and the driver, a restricted view of the front seat passenger, and a view of the roadway.

- Camera 1 was located behind the center internal rear-view mirror, providing a view of the forward road/traffic;
- Camera 2 was embedded in the internal rear-view mirror (behind a hole, 10 mm in diameter), providing a view of the driver and the front seat passenger;
- Camera 3 was embedded in the front cabin light enclosure, providing a view of the steering wheel, center radio console, and the driver's lap;
- Cameras 4 and 5 were positioned in the interior roof of the vehicle, within the DVD player/interior light cavity;
- Cameras 6 and 7 were embedded in the handle above the door in the rear passenger compartment, one on left and one on right and
- Camera 8 was located in the rear parcel shelf, providing a view of the road/traffic to the rear.

All cameras were connected to the data acquisition unit stored in the trunk (boot) of the study vehicle. The video system was operated by a microcontroller, programmed to allow for automatic start-up within 60 s of study vehicle 'ignition on.' The recording system could also be de-activated manually by pressing a red button on the dash behind the steering wheel. This feature was necessary to satisfy ethics requirements and allowed drivers to opt out of the study temporarily by shutting down the recording system at the start of, or during, a trip.

#### *2.1.3. Mobileye™ camera*

In addition to the conventional video system, a Mobileye™ vision system was installed. This optical vision system, which includes motion detection algorithms, was used to log data on road signs, headway distance, lane departures, and pedestrian detection. Audio warnings to the driver were de-activated during the data collection period.

#### *2.1.4. Microsoft Kinect™ for Windows system*

A Microsoft Kinect™ system, composed of an RGB camera and depth sensor, was installed above the rear-view mirror in the 2006 GM Holden Statesman to provide 3D motion capture of the rear seat outboard occupants (Fig. 1). The dimensions of the 2007 Holden Calais did not permit installation of the Kinect™ system. The depth sensor consisted of an infrared laser projector combined with a monochrome CMOS sensor, which captured motion data. Both the raw data stream and built-in skeletal tracking mode, the latter of which was designed to track the 3D location of the head, neck, and shoulders of up to two seated rear row occupants, were available. In the targeted range of 1.5 m (distance between Kinect™ and rear seat back), the Kinect™ was reported to have an upwards and lateral x/y resolution of 3 mm and a depth resolution z of 1 cm. Kinect™ was calibrated to operate in 'near mode' in order to accurately capture child occupant movement within the dimensions of the vehicle interior. Data from the Kinect™, Mobileye™, and video camera systems were synchronized with the VBOX data by matching the time stamps on each data stream. (See Fig. 2.) Q9

Customized software was developed to initiate automatic data collection for the Kinect™ system upon vehicle ignition and log various streams of data. A configuration file allowed the researchers to specify the relevant settings for the application. The application was developed in the C++ language using Microsoft Visual Studio 2012 and the Kinect™ for Windows v1.7 SDK.

These settings included:

- Near mode: Set to operate in near mode providing a range of 500 mm to 3000 mm.
- *Seated mode*: Set to operate in seated mode providing access to up to 10 joints.

**Fig. 1.** Embedded Kinect™ for Windows.



Please cite this article as: Loeb, H., et al., Automated recognition of rear seat occupants' head position using Kinect™ 3D point cloud, *Journal of Safety Research* (2017), https://doi.org/10.1016/j.jsr.2017.10.005