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Residential Elevator Child Entrapment Virtual Reality Accident Reconstruction Methodology

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Abstract: A human factors accident reconstruction was conducted utilizing Virtual Reality (VR) methods to analyze the circumstances surrounding a residential elevator two-year-old child entrapment fatal accident in Arkansas. The application of VR shows how innovative scientific approaches can assist technical investigators in understanding and reconstructing an unwitnessed accident to efficiently converge on a precise incident scenario. The primary goal of this investigation is to make residential elevator designers, manufacturers, installers, inspectors, safety code committee members, government officials, and users more aware of the child entrapment hazard and to identify a novel accident reconstruction methodology that can be used to evaluate design alternatives as appropriate risk reduction measures.

Keywords: Residential Elevator Child Entrapment, Virtual Reality, Accident Reconstruction Methodology

1. Residential Elevator Child Entrapment Safety Hazard History

Despite the fact that, in many states, residential elevators are covered by a consensus safety standard (ASME A17), a potential child entrapment and crushing hazard still exists in some design/installation conditions. Previous studies by the lead author analyzed a ten-year-old child residential elevator crushing accident in South Carolina on November 26, 2013 in which the control circuit allowed the elevator car to move with the accordion door open (Brickman, 2016). The child's catastrophic brain injury prompted a March 19, 2015 recall of about 240 residential elevators that posed a crushing hazard when the elevator was able to operate with the accordion door open, as reported by the U.S. Consumer Product Safety Commission (CPSC) (U.S. CPSC, March 2015). The CPSC staff is aware of eight incidents, including five fatalities, associated with residential elevator child entrapments between fully closed elevator car and hoistway doors between 1981 and 2016 (U.S. CPSC, March 15, 2017). Additional research by the lead author has investigated the child entrapment of a three-year-old boy between the hoistway door and the elevator car accordion door in his Georgia home on December 24, 2010 (Brickman, 2013 and Brickman, 2014). Further similar residential elevator child entrapment incidents have been reported to the U.S. CPSC in which a five-year-old girl became trapped between an elevator car accordion door and hoistway door in Hermosa, California on December 23, 2014 (U.S. CPSC, August 2015) and again for another five-year-old girl in Destin, Florida on June 26, 2015 (U.S. CPSC, October 2015). The residential elevator child entrapment case study presented in this paper addresses the fatality of a two-year-old boy on February 1, 2017 in Little Rock, Arkansas in a scenario similar to the three-year-old Georgia boy (U.S. CPSC, March 17, 2017). The two-year-old Arkansas boy's death was reported to the U.S. CPSC on March 17, 2017, one week before the CPSC voted to deny Petition 15-01, which requests that the CPSC issue a mandatory safety standard for residential elevators to address an entrapment hazard between the elevator car door and the external hoistway door (U.S. CPSC, April 2017).

2. Methods

Previous research has examined biomechanical and human factors analyses methods applied to accident reconstruction involving consumer products and industrial equipment (Knox, 2015 and Knox, 2016). These scientific methods include evaluation of data and information acquired from many sources, including physical experiments, surrogate studies, research literature, modeling and simulation, laws of physics, investigative reports, photographs, and other data gathered about the accident, and witness statements or testimony. This paper introduces the application of Virtual Reality (VR) methods for scientific and engineering accident investigations.

VR has historically been used for training and graphical presentation purposes. A notable VR device in the field of aviation was the Link flight trainer developed in 1929 by Edwin Link; it was used to safely train pilots to fly airplanes using instruments. This full motion simulator illustrates how sensory inputs perceived outside the visual system can be a critical part of the training process (ASME, 2000). In the late 1960s, the Sword of Damocles appeared as one of the first Head Mounted Displays (HMDs) that tracked head movement of the user and displayed primitive graphics to provide the user with a sense of depth in the imagery (Pimental, 1994). The Oculus Rift and HTC are the current state of the art consumer level VR devices that utilize HMDs to provide an immersive visual display useful for simulating visual environments.

In this paper's novel application, VR was used not just to display graphics but as a tool to perform the engineering analyses. Utilizing VR in accident reconstruction is a valuable investigative method that is based upon three-dimensional data acquisition of the product and environment at the scene (by a FARO laser scanner). The scan point cloud data is then modeled in three dimensions using 3D Studio Max software. The modeled surfaces are much more amenable to display. In the proper software, they have material properties, can be textured, reflect light, and appear more realistic than the point cloud data that provide accurate dimensional information. This scene data next is integrated into the VR interface. Then the VR experience allows the investigator to virtually enter the surroundings and to interact with the product in various body positions. With VR, the investigator can be virtually placed and make observations from locations where a human or camera cannot be placed in the actual scene, due to either physical or safety constraints. In addition, the investigator can use the VR interface from the perspective as both an adult and a child to evaluate the variety of interactions possible by users of different body sizes. The VR technology gives the investigator the ability to examine the product at various points in time during product movement to gain a better appreciation of the accident sequence. This VR presentation and analysis technique creates a new tool that can be used to supplement and confirm more traditional accident reconstruction scientific methods.

3. Residential Elevator Virtual Reality Application Example Case Study

3.1 Accident Reconstruction

On February 1, 2017, a two-year-old boy became trapped between the residential elevator accordion door and the first floor hoistway door in Little Rock, Arkansas. At the time of the accident, the injured boy was 29 months old, was 36 inches tall, weighed 32.5 pounds, and had an approximate head circumference of 20.5 inches. The application of VR was used in conjunction with evaluation of collected scene geometry data, child anthropometry, child dummy experiments, live child surrogate testing, medical injury data, and photographs of the child in his final resting position. This analysis determined an animated incident sequence shown in Figure 1. Frames 1-3 in Figure 1 illustrate how the boy enters the space between the car accordion door and the first floor hoistway door; he then becomes entrapped after he closes the hoistway door. In frames 4-6, the elevator car automatically rises past the boy's torso to the second floor. Frames 7-9 depict the injury sequence where the lowering car crushes the boy positioned beneath the car. The two-year-old boy's cause of death was determined to be accidental traumatic compressional asphyxia.

3.2 Potential Child Body Positions

The VR method was effective in exploring various potential body positions between both fixed and moving objects in the physical scene to efficiently converge on a precise relative location of the elevator car, doors, and child that was consistent with the results of the other previously described scientific methods. Figure 2 displays a montage of various child body positions that were evaluated. In Figure 2, the hoistway door is closed and the vertical path of the elevator car is represented by the red plane. Frames 1A (rear view) and 1B (top view) in Figure 2 show the child standing on the sill edge with his head turned to his right where his body is completely clear of the elevator car travel path. All other body positions (kneeling, sitting, standing facing straight ahead, and standing facing sideways) of the child in Figure 2 will result in the boy's body being contacted by the rising elevator car. Because the boy did not sustain permanent external injuries or bone fractures as a result of the incident, the body position in frames 1A and 1B was confirmed and the other body positions in frames 2-5 were ruled out.

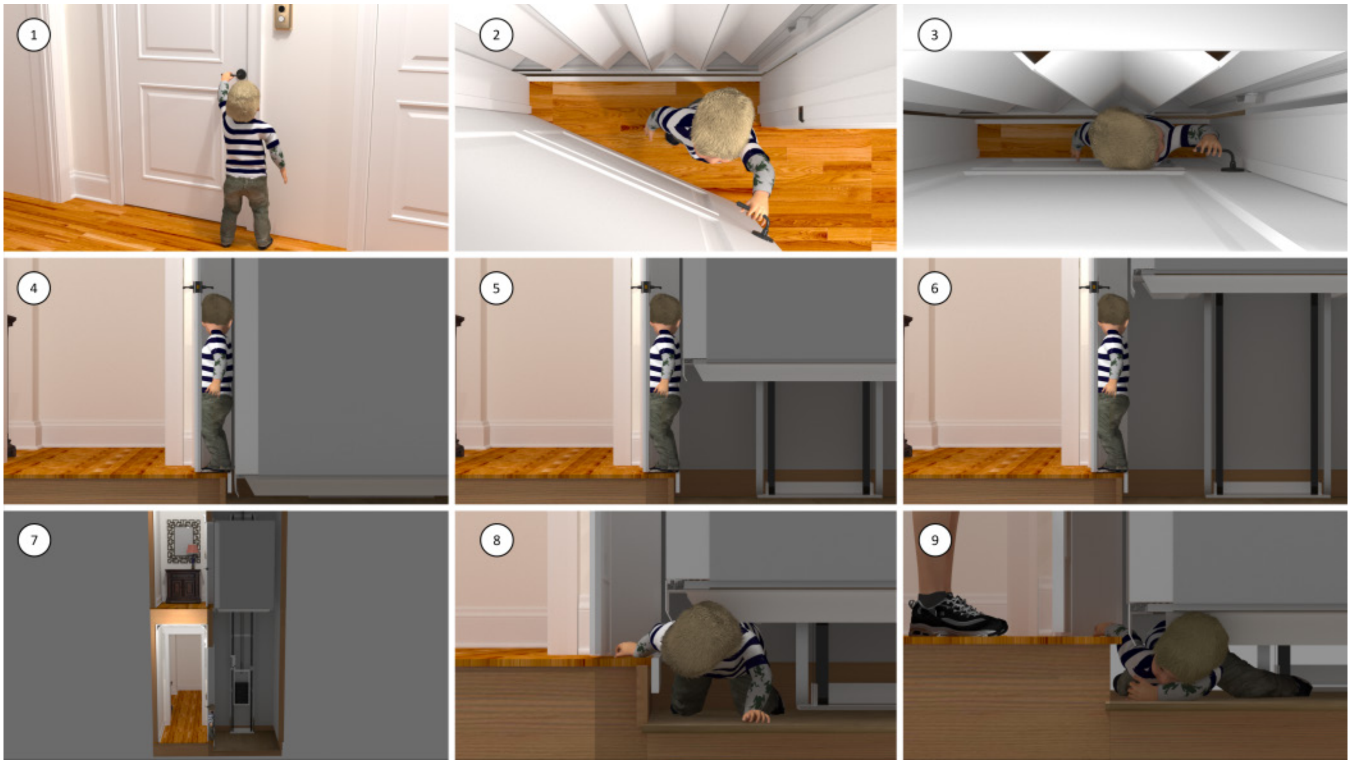

Figure 1. Animated Incident Sequence

3.3 Applied VR Visualization

By wearing the Head Mounted Display (HMD), the investigators were able to virtually explore the specific home and residential elevator associated with the two-year-old boy's incident. The VR tool facilitated real world elevator functions, demonstrating actions and environmental responses such as opening and closing the hoistway door and accordion door, pressing the elevator call buttons, and moving the elevator car up and down. In addition, the investigator could vary the perspective by moving around in the environment or interacting in either adult size or in child size. Figure 3A shows how an investigator can open the hoistway door by using a hand control to enter the elevator space. Furthermore, artificial lighting was developed into the virtual model to illuminate the elevator shaft underneath the car. The VR technology allowed the investigator to virtually become trapped between the closed hoistway door and the accordion door in the two-year-old boy's position and experience the elevator car moving in that environment. Figure 3B displays how an investigator can be virtually positioned underneath the elevator and can be virtually crushed by the lowering car activated by the hand control.

3.4 Evaluation of Risk Reduction Measures

In addition to this accident reconstruction, the VR technology can be utilized to efficiently and safely evaluate various design alternatives as risk reduction measures. For example, various alternative design features such as safety light curtains, car gates, and space guards can be analyzed in the virtual model to explore not only feasibility in that space but also the effectiveness in various residential elevator child entrapment scenarios. Figure 4 depicts one retrofitted space guard installed to the inside of the hoistway door. VR can be used systematically to efficiently evaluate a variety of such space guard designs and validate each design's effectiveness as a child entrapment prevention technique.

Figure 2. Potential Child Body Positions

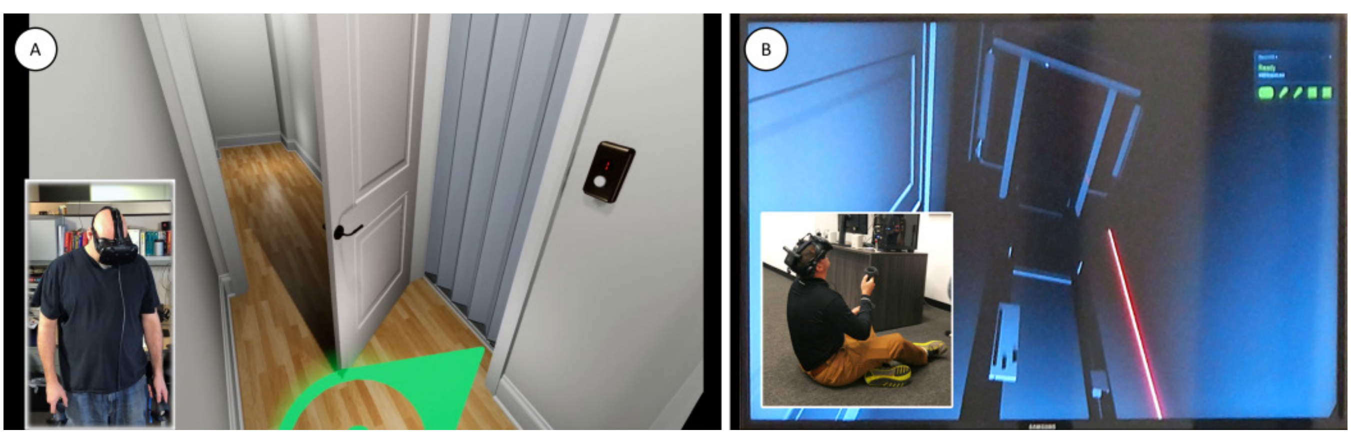

Figure 3. VR Investigations (A - Elevator Space Entry; B – Lowering Elevator Crush Position)

Figure 4. Retrofitted Space Guard with Blue Child Dummy

4. Conclusions

Implementation of VR as a new product safety analysis and accident reconstruction method provides many benefits in terms of efficiency, accessibility and permanence, safety, and safety code development. The application of VR proves useful as a scientific and engineering analysis technique that can enhance traditional scientific methods (such as physical testing and computer modeling) to help investigators understand and reconstruct an unwitnessed accident. Powerfully, VR transports investigators into the environment to see for themselves how and why the accident might have happened. The practical use of VR technology in a real-world scenario brings to life how science and technology can come together to efficiently converge on a precise accident scenario and to safely analyze alternative designs to prevent future similar incidents. The primary goal of this investigation is to make residential elevator designers, manufacturers, installers, inspectors, safety code committee members, government officials, and users more aware of the child entrapment hazard and to identify a novel accident reconstruction methodology that can be used to evaluate design alternatives as appropriate risk reduction measures.

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