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Intelligent Virtual Reality Tutoring for Child Pedestrians

Abstract
This article describes a novel approach for practical child pedestrian training. Instead of exposing children to the dangers and limitations of real roadside training, this approach utilizes an intelligent, Virtual Reality (VR) based training system called *SafeChild*. It provides a realistic open-ended training environment in which children can practice traffic safety exercises. We describes notable features of the system, such as support for different interface setups, interchangeable environments and the use of an Intelligent Tutoring System (ITS), as well as preliminary findings.

1 Motivation

Children, especially between the ages of five and nine, are an endangered group of traffic participants (Snyder & Knoblauch, 1971). Not only are their sensor and motor skills not yet fully developed, but they also lack the knowledge and experience about how to behave correctly in traffic. Further, they are fragile and hard to see for other traffic participants. Therefore, effective traffic education is extremely important for this age group which must include teaching theoretical knowledge as well as a fair amount of practical exercises (Percer, 2009). However, practical training in this domain is associated with a number of difficulties. Letting children practice in real traffic environments exposes them to potential danger and therefore certain prerequisites must be ensured before training can be conducted. For instance, traffic density and speed need to be sufficiently low at the time and place of training and specialized personnel must be present to organize and overlook the procedure. This makes it hard for educational institutions to provide a sufficient amount of practical traffic safety training to their students. In order to deal with this problem, Virtual Reality (VR) Training seems like a promising solution. ~~In this setting,~~ the real road is substituted by a realistic but safe virtual environment and previous studies have confirmed great potential of this approach (McComas et al., 2002, Thomson et al., 2005). The *SafeChild*[1] system presented in this article builds on the success of the these studies and aims at bringing VR training one step closer to actual use in schools and kindergartens by using state-of-art technology from the entertainment industry and research in technology-enhanced learning.

2 Related Work

There are several studies about the use of VR as a tool for child pedestrian safety training. In 2002 McComas et al. report a study with fourth to sixth grade students attending urban and suburban schools. Through a VR intervention, the participants were supposed to learn several pedestrian safety behaviors. As a result of the intervention, children showed significant improvement within the VR application and those from the suburban school transferred improved behavior into real-world behavior. The VR system used consisted of three monitors, a simulation with eight different crossings and a head tracking device to determine head movement. A later study published by Thomson et al. in 2005 focused on the skill of finding appropriate gaps in traffic to cross a road. Study participants were 7, 9 and 11 years old and the training was conducted using a VR system that let the user examine traffic and decide the moment to initiate crossing. The results were also very positive and showed, for instance, that children crossed faster, were able to estimate their crossing times better and improved in finding safe opportunities to cross after training in VR. Another study was published by Schwebel et al. in

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[1] The system was developed in the *SafeChild* project (2013-2015) which is funded by the BMBF (grant 01IS12050) within the frame of the *Software-Campus* program. Further information can be found under the following URL http://scweb.celtech.de

2008. Instead of focusing on learning results, the goal of this study was to proof the validity of a specific VR system as a tool to understand and prevent child pedestrian injury. The system consisted of three monitors that showed one road with traffic (Figure 1). The user could initiate crossing by either shouting or taking two steps forward. The actual crossing is then performed automatically without further influence of the user. The outcome of their study indicates that behavior in the real world validly matches behavior in their VR system. As described by Schwebel et al. (2014), the authors have also started to study a similar, internet-based VR system.

Figure 1: VR environment used Schwebel et al. 2008.

In summary, it can be concluded that the above mentioned studies all confirm the great potential of VR for child pedestrian safety. However, the VR systems that were used served mainly as simulators while the tutoring task was carried out by human tutors. Moreover, those systems trained different aspects of traffic safety and offered a fixed set of exercises that are the same for every user. In the case of Schwebel et al. 2008, Schwebel et al. 2014 and Thomson et al. 2005, interaction was also very limited. We believe that by increasing flexibility while decreasing dependence on human assistants would greatly benefit a broader dissemination of VR training. With this in mind, the next section presents the *SafeChild* system and how these principles have been implemented in the software.

3 *SafeChild*

Following the idea to create a VR training system that is highly flexible and mostly independent of human tutors, *SafeChild* offers an open environment, a wide range of exercises, different interface setups as well as an Intelligent Tutoring System (ITS) that conducts and adapts the teaching task within the system (Corbett et al. 1997). This section will first present the overall architecture of the system and subsequently describe the individual components.

3.1 Architecture

The *SafeChild* Architecture consists in general of three major components. The city simulation including traffic and an urban neighborhood is the core of the architecture and generates the virtual training environment. The interface component connects the user to the city simulation and supports different hardware setups, varying in degree of immersion, availability and cost. On the other side, the city simulation is also connected to the ITS. The ITS analyzes information from the city simulation and adapts the training to the individual needs of the user. Figure 2 shows the architecture graphically.

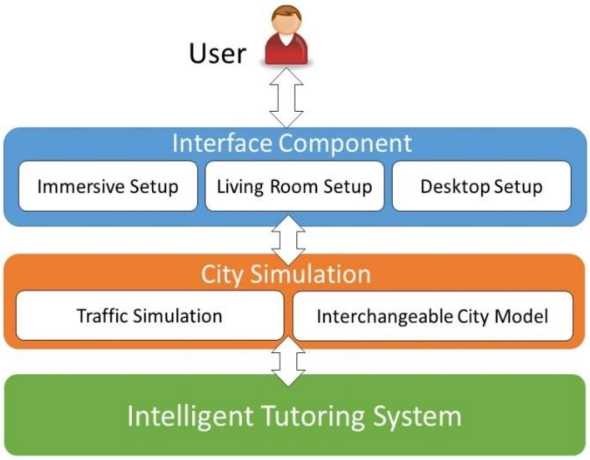

Figure 2: *SafeChild* System Architecture

3.2 City Simulation

The city simulation was developed using the popular Game Engine Unity and consists of a Multi-Agent traffic simulation as well as realistic 3D models of urban architecture (Figure 3a). A waypoint system is placed along the roads of the virtual city to direct and control traffic (Figure 3b). Cars are generated at dedicated waypoints with a certain degree of randomness in terms of waiting period, type of car and speed. Because of the randomness, each time the simulation is started, the user will encounter different traffic situations, just as in the real world. After a car is generated, it is controlled by an artificial intelligence agent. The default behavior of the agent is to simply get from one waypoint to the next. However, it will react to traffic facilities such as traffic lights and zebra crossings, adapt its speed if the car in front of it is slower and choose at random between different subsequent waypoints if there are multiple waypoints connected to its current goal. The movement of the cars is based on the physics simulation of Unity in order to achieve realistic acceleration and breaking behavior.

3a Virtual City 3b Waypoint System

Figure 3: *SafeChild* City Simulation

The traffic simulation is not restricted to work with only one urban environment, but can be adapted to different environments and road networks. Therefore, the appearance of the virtual training environment can be altered by changing the 3D models. For this project we utilize not only third party models of stereotypical urban architecture to create virtual cities, but are also working together with the surveying office of Saarbrücken, Germany, to integrate models based on real measurements of the city. While artificial cities can be used to create specific training situations, using real city models increases the degree of realism and allows children to practice routes from everyday life, such as their actual route to school.

3.3 Interface

With the advances of the digital entertainment industry, there are nowadays a wide range of display and input devices on the consumer market that can be used for interactive real-time 3D applications to achieve different levels of immersion. In theory, a high level of immersion leads to more natural behavior and thus promises better learning results (for instance shown in Coulter et al. 2007). However, due to temporal, spatial and budget restrictions, the requirements for a highly immersive interface cannot always be met. Therefore, *SafeChild* supports different kinds of interface setups.

3.3.1 Immersive Setup

The display component of the immersive setup in *SafeChild* consists of three active stereoscopic monitors arranged in a semi-circle which enables a 3D view into the virtual world in a visual angle of 180 degrees. As interaction device a Microsoft Kinect Sensor is used, whichperforms full body tracking of the user. A powerful computer with high-end video hardware is required to run this setup and although only consumer products are used, it is still considerably more costly than the other setups listed below. Furthermore, this setup is time-consuming to install and therefore also difficult to move. Because of these properties, the immersive setup fits best in large educational facilities such as schools or kindergartens. Figure 4 shows a picture of this setup.

The user experiences the virtual training environment in a natural way and can move within the virtual world with body gestures. A total of four different gestures have been implemented in *SafeChild*: one for rotation and three for translatory movement. Depending on user preference, the gesture for translatory movement can be chosen and selected during runtime. A brief overview of the gestures are given below, while a detailed description can be found in Rump, 2014.

Figure 4: *SafeChild* Immersive Setup

Rotation

The forward orientation vector is orthogonal to the line that goes through both shoulders of the user. Therefore, by turning the shoulders, rotation in the virtual world can be achieved. As depicted in Figure 5, the degree of rotation is controlled by the angle λ between the original orientation V_0 and the new orientation V_1.

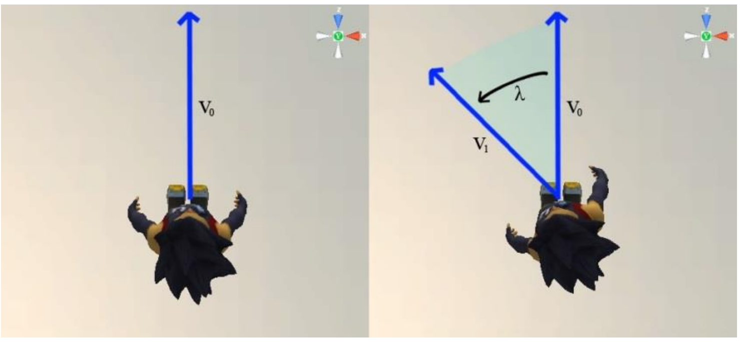

Figure 5: Rotation Gesture in *SafeChild* (Rump, 2014)

Translation

For translational movement, there are three different gestures which requires the user to either lean forward, walk in place or to move a certain distance from a predefined center point.

LEAN: As depicted in Figure 6, forward movement is achieved through leaning forward and speed of movement is controlled by the magnitude of leaning angle λ.

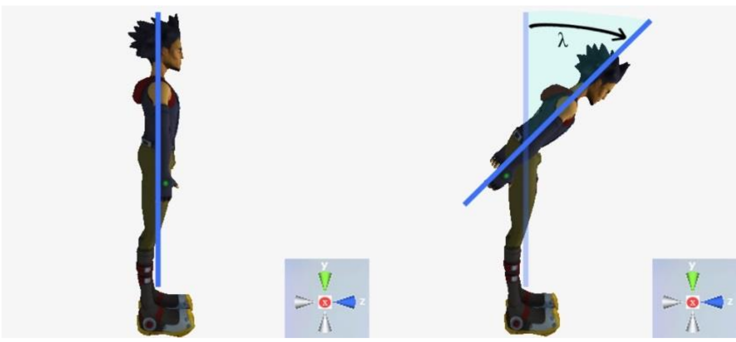

Figure 6: LEAN (Rump, 2014)

Walking-In-Place: To move forward, the user walks in place by raising left and right leg alternately. As Figure 7 shows, a certain height threshold must be achieved.

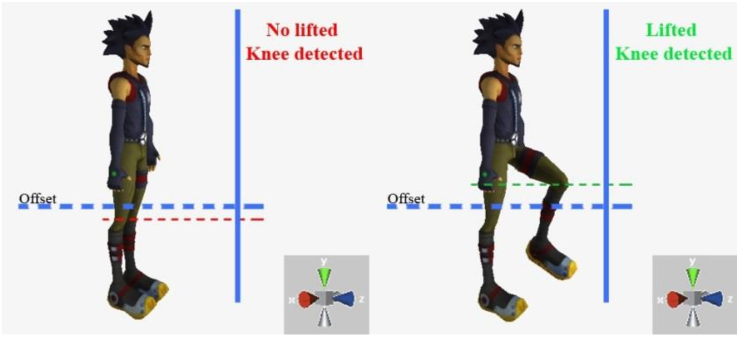

Figure 7: Walking-In-Place (Rump, 2014)

Distance-To-Velocity: for this gesture, the user needs to define an initial position first. Afterwards, movement is controlled by stepping away from the initial position as indicated by vector V_0 in Figure 8. Distance and direction of the vector controls the actual movement in the virtual world.

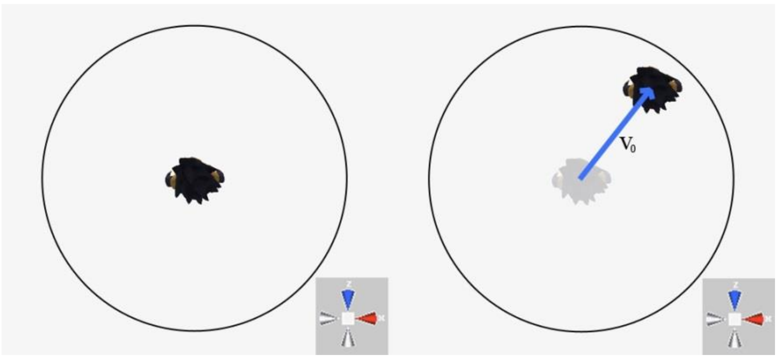

Figure 8: Distance-To-Velocity (Rump, 2014)

3.3.2 Living Room Setup

In the living room setup the three active stereoscopic monitors are replaced by a single television screen, while the interaction is still handled by a Microsoft Kinect sensor. Although the display component is less immersive compared to the above mentioned setup, it still provides the natural way of interaction. This setup fits in an average living room and a mid-level computer is sufficient to run it. Since most components of this setup can be found in an average household, it only requires minor additional costs to be used in a home setting.

3.3.3 Desktop Setup

The desktop setup uses a standard monitor or notebook screen as display with keyboard and mouse as interaction devices. The degree of immersion is inferior compared to the other setups in terms of visual representation and interaction. Instead of being surrounded by the virtual world, this setup is more of a window into it and instead of interacting directly through body gestures, keys and buttons are used. However, the vast majority of computers are operated using these devices and thus in most cases no additional costs are required to run *SafeChild* in this setup. Also, since notebooks have built in keyboards and pointing devices, the mobility of this setup is superior. Furthermore, *SafeChild* can run in this setup either as standalone application or directly from a standard web-browser. In the latter case, an Internet connection is sufficient to access *SafeChild*. In summary, the desktop setup is a light-weight alternative for such cases where the immersive or living room setup are not available due to cost or spatial reasons.

To conclude, *SafeChild* supports three interface setups that differ in terms of requirements and degree of immersion. Figure 9 illustrates the different setups next to each other. Future research is required to determine the differences in learning results for each interface setup and the trade-off between effectiveness of learning and cost.

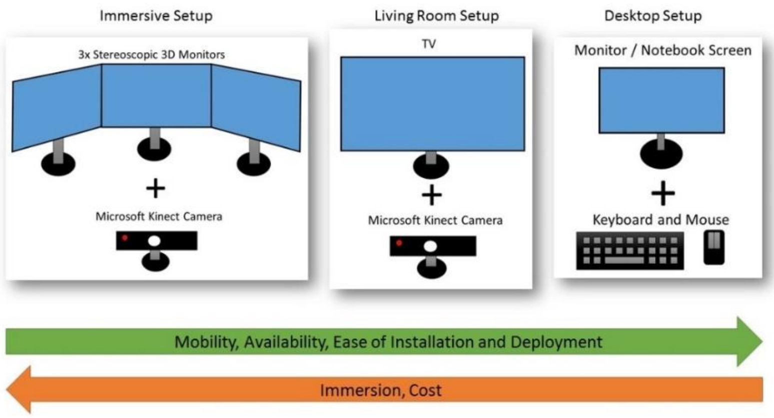

Figure 9: *SafeChild* Interface Setups

3.4 Intelligent Tutoring System

In order to reduce the need for presence of human tutors while conducting VR training, the *SafeChild* system provides build-in tutoring capabilities. It offers a set of different exercises for various traffic situations. An Intelligent Tutoring System (ITS) is employed to adapt these exercises automatically in a way that should optimize learning results. However, in order to verify the effect of adaptation to learning performance, long-term interdisciplinary research is required with experts from psychology, pedagogy, traffic safety and computer science. *SafeChild* has not yet reached this level of maturity and therefore the functionalities described here should be regarded as preliminary and as basis for further research and development. In particular, functionalities associated with Student Modeling and exercise customization will be described below.

3.4.1 Student Modeling

Student Modeling is the term for User Modeling within ITS literature (VanLehn, 1999) and describes the process of building up a model of the current level of knowledge and skills of the user based on interaction data with the system. The Student Modeling approach used in *SafeChild* is a subject of ongoing research (Gu & Sosnovsky, 2014). It first creates a dynamic model of the users' perception using ray casting (Figure 10) and subsequently employs a rule-based system to derive higher-level cognitive traits of the user, such as awareness or exploration strategy.

Figure 10: Raycasting to Determine Object Visibility

3.4.2 Exercise Customization

The general task in each exercise is to walk safely to a goal position, that is clearly indicated to the user. Besides changing start and goal location, the exercises can also be customized by adding additional objects, changing the type of crossings, changing traffic parameters such as density or speed and weather conditions such fog. In this way, the degree of difficulty as well as the required skills within an exercise can be altered. Two examples are given here. Figure 11 shows two traffic light exercises. While in one exercise (Figure 11a) it is sufficient to apply the rules for crossing at a traffic light, the other requires the user to find the traffic light and to walk there first (Figure 11b)

11a Traffic Light Exercise 1

11b Traffic Light Exercise 2

Figure 11: *SafeChild* Traffic Light Exercises

The second example is illustrated in Figure 12. Here two exercises for crossing without supervision are shown. While the field of vision is clear in the first exercise (Figure 12a), there is a garbage truck blocking the vision to the left in the second one. This requires the user to first find a place where his/her vision is not blocked before starting to observe traffic for crossing.

12a Unsupervised Road Exercise 1

12b Unsupervised Road Exercise 2

Figure 12: *SafeChild* Unsupervised Road Exercises

Based on information given by Student Modeling and by using the customization possibilities within exercises, several exemplary adaptation functionalities have been identified and will be implemented in the next iteration of the system:

- If the user does not see an important object, display a warning.
- If the user does not use the traffic light to cross although he/she saw it, consider exercise outcome as failure.
- If the user takes too long to complete an exercise, reduce traffic density and speed.
- If the user fails an exercise, choose an easier one next.

As discussed in the subsequent section, the value of these adaptation functionalities to learning has yet to be determined and at this point they are mainly to demonstrate technical possibilities.

4. Discussion

As presented above, *SafeChild* is already at an advanced state from a technological point of view. However, there is still a long way to go, before the system can be used by children on a regular basis. Because of the novelty of the system, a variety of open research questions from psychology and pedagogy need to be addressed to determine how and when to utilize the system to benefit child pedestrian education in the best way. Therefore, no formal evaluation has been performed yet to determine the impact of *SafeChild* to knowledge or skill acquisition. Instead, the system was displayed at exhibitions such as the CeBIT 2014 and presented individually to parents, teachers and traffic safety experts. The feedback obtained through discussions indicate that the general attitude towards the approach is positive. The simulated environment was perceived as realistic and the potential to train different traffic scenarios, especially dangerous ones, was well received. At the same time the need for further research on training design was also confirmed. For instance there were different opinions about the degree of danger that children should be allowed to encounter in the simulated environment. While some argue that they should not be exposed to virtual traffic accidents, others believe that they would help children in understanding the importance of safe behavior. Further questions include which age range is appropriate for this kind of training and how well knowledge or skills acquired in the virtual world can be transferred to the real world.

Based on this preliminary feedback, the future work will focus on developing curricula for traffic safety education together with domain experts that incorporate the *SafeChild* system. At the same time, these curricula will guide the further development of the system itself and especially the ITS component. Depending on the eventual success of *SafeChild* for child pedestrian training, the system can be expanded to other related domains such as pedestrian safety for elderly or driving safety.

5. Conclusion

This article presented *SafeChild*, a novel system to teach practical traffic safety skills to young children using an intelligent VR based training application. In comparison to previous approaches of VR pedestrian training, it aims at improving flexibility in terms of interface setup and simulated environment while reducing the dependence on human tutors through the use of an ITS. Despite the fact that *SafeChild* is a prototype and certain components are still in an immature state, the first results are promising and the system provides a solid technical foundation for further interdisciplinary research and development. This includes research towards integration of VR training into child pedestrian safety curricula, definition of adaptive functionalities for this domain and overall understanding of the capabilities of modern IT technology to create intelligent VR training applications for a broad range of users.

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