A Novel Virtual Reality Driving Environment for Autism Intervention

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Abstract. Individuals with autism spectrum disorders (ASD) often have difficulty functioning independently and display impairments related to important tasks related to adaptive independence such as driving. Ability to drive is believed to be an important factor of quality of life for individuals with ASD. The presented work describes a novel driving simulator based on a virtual city environment that will be used in the future to impart driving skills to teenagers with ASD as a part of intervention. A physiological data acquisition system, which was used to acquire and process participant's physiological signals, and an eye tracker, which was utilized to detect eye gaze signals, were each integrated into the driving simulator. These physiological and eye gaze indices were recorded and computed to infer the affective states of the participant in real-time when he/she was driving. Based on the affective states of the participant together with his/her performance, the driving simulator adaptively changes the difficulty level of the task. This VR-based driving simulator will be capable of manipulating the driving task difficulty in response to the physiological and eye gaze indices recorded during the task. The design of this novel driving simulator system and testing data to validate its functionalities are presented in this paper.

Keywords: Virtual Reality, Autism intervention, Adaptive task, Physiological signals, Eye gaze.

1 Introduction

Individuals with autism spectrum disorders (ASD) often have difficulty functioning independently and display impairments related to important tasks related to adaptive independence such as driving [1]. ASD has a 1 in 88 prevalence rate in the US with a very high familial and societal cost [2-4]. Given this high prevalence, ASD has been recognized as an important public health concern and the development of safe and

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efficacious interventions for individuals with ASD has been identified as a priority research area [5].

There is an increasing consensus that adaptive tasks (also known as skill training) and educational intervention programs can significantly improve long-term outcomes for individuals and their families [6]. Due to the alarmingly increasing prevalence rate of the disorder and the lack of trained therapists, technology-based assistive ASD intervention has gained momentum in recent years [7].

A growing number of studies have been investigating the application of virtual reality (VR) in ASD intervention [8-11]. Virtual reality is a type of computer-assisted technology (CAT) that allows a high degree of user-control and interactivity between the user and electronic media. Through its ability to create dynamic, multisensory, “real-life” stimulus environments, within which all behaviors of the task could be recorded [12], VR potentially offers ideal tools that are not available using traditional intervention methods.

Many individuals with ASD are approaching adolescence and young adulthood; however, interventions to assist in the promotion of skills related to independent living, often referred to adaptive behavior skills, are lacking. At present, only a handful of studies have been conducted exploring the use of VR for enhancing adaptive behavior skills [13-15]. Further, most VR systems applied to adaptive tasks solely use task performance or explicit user feedback as primary means of evaluation and thus lack adaptability [13-15]. The present study aims at filling this gap by incorporating implicit feedback and state detection using physiological signals and eye tracking information during a driving task in an adaptive virtual reality environment. Driving rules are embedded within the environment to adjust difficulty levels to allow individualized skill development by switching to an appropriately challenging level of driving based on both performance and affective states (e.g., engagement, enjoyment, frustration etc.).

The paper is organized as follows. The scope and objectives of this paper is presented in Section 2. Section 3 describes our proposed framework of the development of VR-based simulator which could automatically detect and respond to the affective cues of teenagers with ASD. The testing of the proposed system to validate its functions is presented in Section 4. Finally, Section 5 summarizes the contributions of the paper.

2 Scope and Objectives

In this paper, we developed a VR-based driving simulator that can acquire physiology and eye gaze signals during the driving tasks. These signals can be utilized to infer the affective states of the participants, which are then used in the design of a feedback mechanism to improve performance. In recent years, several studies have reported the design of driving simulators, which mainly focused on driving assessment [16] or driver stress monitoring [17]. To our knowledge, the study on the correlation of utilizing real-time physiology and eye indices as feedback to manipulate the difficulty level in the driving task has not been known. Commercial, off-the-shelf driving simulators are not suitable for this research since proprietary software issues prevent the users from designing new driving tasks with embedded intervention rules as well as integrating the simulator with both physiological and eye gaze measurement systems. While head-mounted devices (HMDs) have been considered to be the best solution for fully, immersive, 3-D VR systems, there are some associated side effects such as cybersickness with the HMD systems, that are not appropriate for ASD population [18]. In this paper, in order to avoid the problems associated with HMD-based VR system, we have developed a desktop VR system that has been shown to be appropriate for ASD population [19].

The objectives of this work are two-fold: 1) to develop a driving simulator using VR technology capable of flexibly responding to subtle affective changes in teenagers with ASD; and 2) to test the functionality of the VR-based driving simulator. Also, we have investigated whether the system could effectively measure physiological and eye gaze indices dynamically, which could potentially be used as feedback to manipulate the difficulty level of the driving task.

3 System Development

The virtual driving skill adaptive task is designed around a virtual city. The overall system consists of components such as a virtual task presentation simulator, a driving interface module, physiological signal-monitoring and eye tracking applications and their associated psychological state and engagement detection modules (Fig. 1).

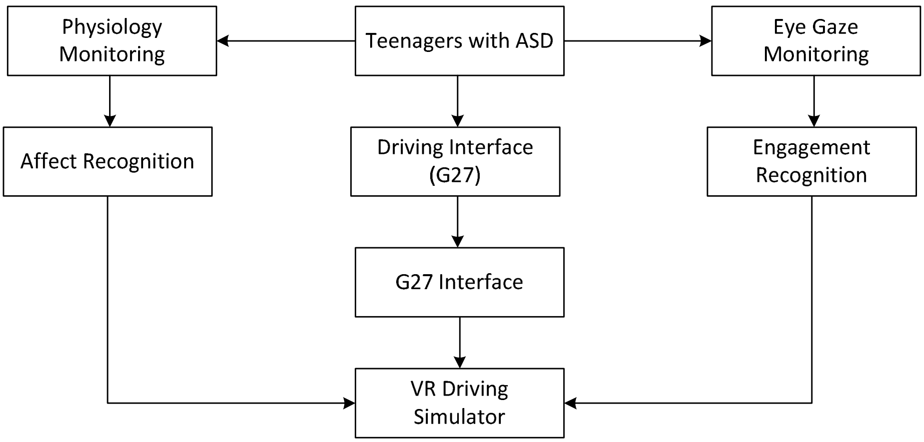

Fig. 1. System diagram of the adaptive driving platform

There are several elements such as facial expression, eye gaze, vocal intonation, gesture and physiology that could potentially be used to evaluate the affective states. However, individuals with ASD often have communicative impairments (both verbal and nonverbal), which contribute to challenges regarding affective expression. These vulnerabilities place limits on traditional communicative methodologies. As such, physiology and eye gaze signals, which may be less intuitive for humans but could be appropriate for computers, can be exploited by using signal acquisition and processing tools.

The Logitech G27 driving device which has a steering wheel, a brake and an accelerator is interfaced with the VR-based driving simulator to make the adaptive tasks more realistic and more easily manipulated by the participants. The main components of the virtual driving adaptive task platform are described below.

3.1 VR-Based Driving Simulator

The virtual city environment was constructed using a procedural 3D content creation tool called CityEngine (v. 2011.2, www.esri.com/software/cityengine). A sample city model – modeled after a downtown area of Philadelphia – was used and expanded significantly to design the city needed for the driving task. The sample model was expanded to four times its original size. The terrain map on which the city rests was duplicated three times and translated appropriately to create a 2x2 grid in order to create the terrain for the larger city. In order to differentiate the quadrants from one another, each new quadrant took on a different regional type. Figure 2 below outlines the layout of the city.

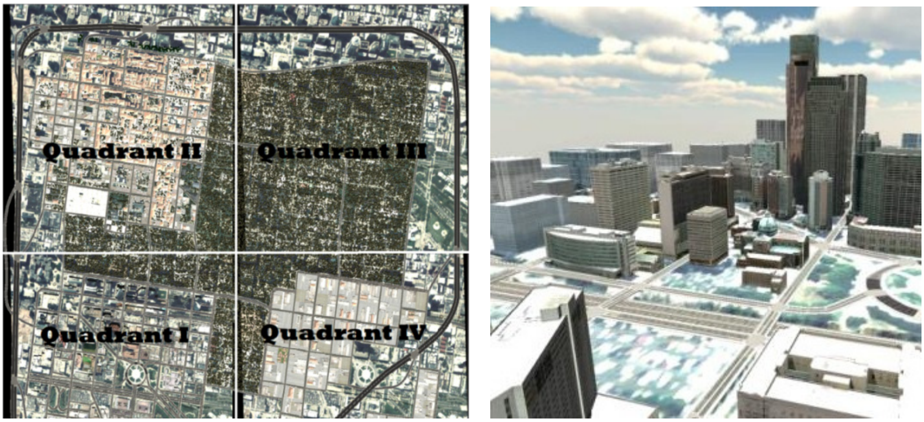

Fig. 2. Aerial view of the city (left) original downtown area (right)

Region I corresponds to the original downtown area. Region II became a residential area, Region III became a large arboreal area with no buildings and few roads, and Region IV became an industrial park. Each of these regions was then bridged to its neighboring regions via streets, bridges, and one large highway system. An eight-lane, bidirectional highway was constructed which encircles the perimeter of the entire city and possesses several entry/exit points that allow vehicles to join and depart from the highway as desired. Traffic lights, pedestrian crossing signals, stop signs, speed signs, highway markings, and various other types of signs were designed using Autodesk Maya. The city has been populated with several vehicles (other than the one that the participant drives) and pedestrians. At present there are several dozen functionally operating intersections with traffic lights; multiple pedestrians of various height, age, race, and gender; and a wide range of vehicles including buses, pickup trucks, SUVs, sedans, and tractor trailers.

The city model was imported into the game engine Unity (v. 3.5.3). Colliders were applied at the time of import to the meshes of all moving models so that they can interact with the sidewalks and streets appropriately. The model car used for the driving simulator was obtained from an online 3D repository and then was customized by removing parts that are not visible from first person perspective, and adding dashboard components such as speedometer and turn signal displays. Fig. 3 shows the first person perspective from the inside of the car. The participant's vehicle is controlled by the Logitech G27 steering wheel, pedals, and gears. The eye tracker application, the physiological monitoring application and the G27 interface are all integrated with the VR driving simulator using network interface in a distributed architecture in which each application is running independently while exchanging data via message passing.

Fig. 3. First person perspective (top) the highway system (left) and an intersection (right)

The driving task is constructed to have various levels of difficulties such as easy, medium, and hard. Tests in the easy range will consist mostly of the participant driving along the road with a specified destination. While progressing towards their destination, the participant will encounter other vehicles on the road and will also have to pay attention to intersections and speed limits. The medium difficulty test will introduce pedestrians crossing roads, cars joining/departing from the highway, a higher number of other drivers, and longer drive paths. The complex/hard level of difficulty will introduce the participant to aggressive drivers; sudden, unexpected stops at high speeds; and other difficult potential anxiety-inducing situations. Throughout the tasks, the participant's eye gaze will be monitored as well as his/her physiological signals to detect the engagement of the participant on the specific task and how the participants feel for adaptively changing the difficulty level.

3.2 Physiological Signal Acquisition and Processing Module

The physiological signals are collected using the Biopac MP150 physiological data acquisition system (www.biopac.com). Various physiological signals are investigated. The acquired physiological signals are broadly classified as cardiovascular activities including electrocardiogram (ECG), impedance cardiogram (ICG), photoplethysmogram (PPG), and phonocardiogram (PCG)/heart sound; electrodermal activities (EDA) including tonic and phasic responses from galvanic skin response (GSR); electromyogram (EMG) activities from corrugator supercilii, zygomaticus major, and upper trapezius muscles; and peripheral temperature. These signals were selected because there is good evidence that shows that the physiological activity listed above associated with engagement and anxiety and can be differentiated and systematically organized.

We developed a socket module to transmit task-related (e.g., trial start/stop) event triggers from the virtual environment being executed on the driving task computer to the Biopac (Physiological Data Acquisition system). Physiological signals along with task-related event triggers were sent over an Ethernet link to a physiological data logger computer to enable acquiring and logging of the signals in a time-synchronized manner with VR-based driving adaptive task.

3.3 Eye Tracker Module

Tobii X120 (www.tobii.com) eye tracker was used for eye gaze tracking, which is a real time eye gaze monitoring system. The X120 has an accuracy of 0.5°[20]. We used the eye-tracker at 60Hz to acquire gaze position.

The eye-tracker is used to measure the eye gaze of the participants during the driving task. Analysis of eye gaze such as gaze fixation and fixation duration and eye physiological signals such as blink rate and pupil diameter can provide important information about the engagement level of a participant. Since the head movement during the experiment is limited, it guarantees a high accuracy with the desktop eye tracker. Such kind of non-contact device is appropriate in the VR experiments dealing with individuals with ASD.

A 9-point calibration was implemented at the beginning of the trial. The eye tracker was placed just under the monitor in which the VR-based adaptive driving task was presented. Participants sat approximately 70cm away from the eye tracker. We recorded the time the participants spent looking at the regions of interest (ROIs) when they were driving in the VR environment. A dynamic eye-tracking algorithm was implemented to keep track of the eye-gaze of the participants and detected its relative position with respect to the moving ROIs.

4 System Testing

The driving simulator was tested for its robustness, operability, flexibility and reliability. Four typically developing individuals tested the system for 30 minutes each. Figure 4 shows some screen shots of the driving task. Their responses showed: 1) the system could be operated easily; 2) the difference in the task difficulty was quite noticeable; and 3) the overall interaction was engaging. Further, both the physiological signal acquisition system and the eye-tracker worked as designed for all participants.

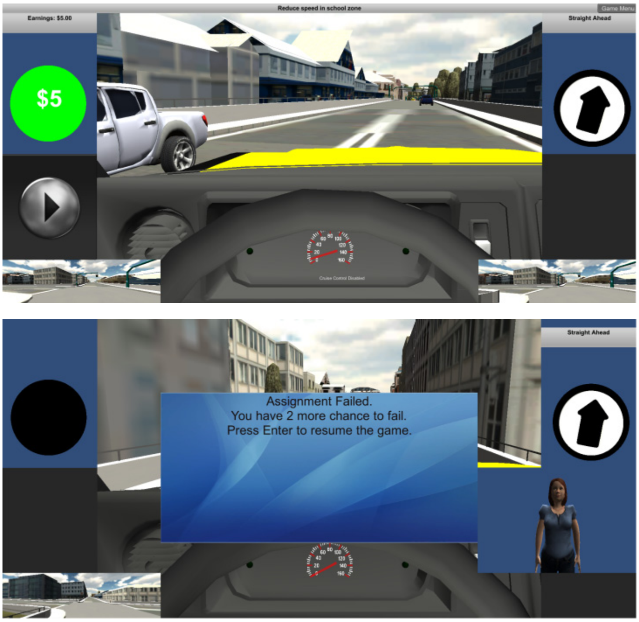

Fig. 4. Task success scenario (up) and Task fail scenario (down)

In our previous work, we successfully integrated the Biopac to several platforms [21-23] and it also worked well with the current VR driving simulator. We can collect all the physiological signals described in Section 3 without noise or artifacts. An off-line feature extraction software is used to extract features from these signals.

The eye-tracker was validated using a typical scenario. We chose four ROIs within the scene that spanned the task presentation monitor screen: the Coca-Cola advertisement, the billboard, the speed limit sign and the traffic light, shown in Fig 5. An on-line detection algorithm was used to detect the gaze position related to the ROIs, i.e., whether the participant's gaze was in the ROI or out of the ROI. Four participants were involved in the validation.

A 3D to 2D mapping algorithm was implemented to get the 2D coordinates on the screen of the four chosen points in the four ROIs. The participants were instructed to look at the points in these regions. The coordinates of their eye gaze were recorded by

Fig. 5. Validation scenario of eye tracker

the eye-tracker and the gaze position related to the ROI was detected online. The result showed that the gaze accuracy was 1.7cm (3.32% of screen width) in the x direction, i.e., from the left to the right. The accuracy was 1.62 cm (6.42% of screen height) in the y direction, i.e., from the top to the down. The drift of gaze position in the x axis was 1.55cm (2.9% of screen width), and the drift of gaze position in the y axis was 1.81cm (7.14% of screen height). These errors are small and are within the range of acceptability for our application and can be attributed to the inherent inaccuracy of the eye tracker and head movement of the participant. For all the participants, we acquired the correct detection results regarding whether the participants were looking into the ROIs or not.

5 Conclusion

The primary contribution of this paper is to present a novel adaptive VR-based driving skill intervention platform for individuals with ASD. The system monitors eye gaze and physiological responses of the participants and can make adjustment of the difficulty levels of driving based on both performance and affective states. The system design is complete and it is able to perform the described tasks with fidelity. A usability study involving teenagers with ASD and typically developing peers as a control group is underway. The experimental design and methods could potentially produce an ideal tool for use in autism interventions surrounding adaptive behavior tasks.

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