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Applied Ergonomics 39 (2008) 379–384

APPLIED ERGONOMICS

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Rectification of legibility distance in a driving simulator

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Received 22 November 2006; accepted 7 August 2007

Abstract

Visual differences lead to differences in the legibility distances of traffic signs between driving simulators and real road environments. To ensure that the legibility distance in a simulator is similar to that in the real world, this study proposes a theoretical equation for predicting legibility distance and a simple algorithm for determining the magnifying power of a traffic sign for a display system in a simulator. Experiments of traffic sign recognition using a simulator were conducted under quasi-static and dynamic driving conditions. On-road tests were also carried out under quasi-static and dynamic driving conditions. Thirty healthy and non-disabled volunteers were recruited. The experimental results showed that the proposed theoretical equation for predicting legibility distance and the simple algorithm for determining the magnifying power of traffic signs reduced the difference in legibility distances between the simulator and real road environment under quasi-static and dynamic driving conditions.

Keywords: Driving simulator; Legibility distance; Traffic sign

1. Introduction

The traffic sign, an integral part of the road environment, imparts important road information to drivers. Drivers need to recognize the sign and then take necessary actions in response to the sign. If drivers fail to recognize traffic signs at the appropriate time, accident probability can increase. Therefore, dynamic legibility, which describes the ability to read a sign moving with respect to a driver, is essential. Detection and recognition of traffic signs has attracted considerable attention. Zwahlen et al. (1995) reviewed relevant legibility literature and provided normalized legibility performance data for comparisons of past legibility research. Additionally, studies investigating dynamic legibility of traffic signs mainly utilized on-road tests to acquire experimental data (Zwahlen, 1995; Chrysler et al., 1996; Dissanayake and Lu, 2001; Zwahlen and Badurdeen, 2002).

Driving simulators are another choice for experiments studying the dynamic legibility of traffic signs, of value due to their safety and controllability. However, a sufficiently realistic simulated world has yet to be achieved and most technologies for producing quality virtual environments require refinement. These insufficiencies make the legibility distances of traffic signs in driving simulators different from those in a real road environment. Therefore, in order to increase the fidelity of driving simulators, rectifying the legibility distance in a driving simulator to reduce the difference between the simulator and on-road testing is necessary. However, previous research that has utilized simulators has usually ignored the visual difference between a virtual scene and the real road environment (Brooks and Green, 1998; Mourant and Jaeger, 2000; Lee, 2002; Sakol and Tawatchai, 2003; Espié et al., 2004). In most studies, a simulator display system was set by either experience or trial and error (Chen, 2003), and no clear explanation was given in the publications for the display system settings chosen.

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0003-6870/$ - see front matter
doi:10.1016/j.apergo.2007.08.002

Therefore, the aim of this study is to reduce the difference between the legibility distance in a driving simulator and that in a real road environment. To reduce this difference, this study proposed a theoretical equation for predicting legibility distance and a simple algorithm for determining the magnifying power of traffic signs in a simulator display system. Experiments for recognizing traffic signs were conducted at various driving speeds, using a simulator and a real car, to validate the algorithm feasibility.

2. Methods

2.1. Theoretical equation for predicting legibility distance

Legibility distance, L^*, where a virtual object is recognized can be easily calculated using a basic formula of similar triangles (Fig. 1) as follows:

$$L^*/w^* = L/w, \tag{1}$$

where w^* is the width of the virtual object in the virtual scene, L the distance between the simulator driver and the screen, and w the width of the virtual object shown on the screen.

The w in Eq. (1), i.e., the width of the virtual object shown on the screen, can be obtained from the following (Fig. 2):

$$w = (a \times C)/a^*, \tag{2}$$

where a is the screen width, a^* the projector horizontal resolution, C the resolution of a virtual object which is set in a virtual scene.

Substituting Eq. (2) into Eq. (1), yields the following equation:

$$L^* = (w^* \times a^* \times L)/(a \times C). \tag{3}$$

Eq. (3), based on the parameters used to set the display system in a driving simulator, is used to predict legibility distance L^*.

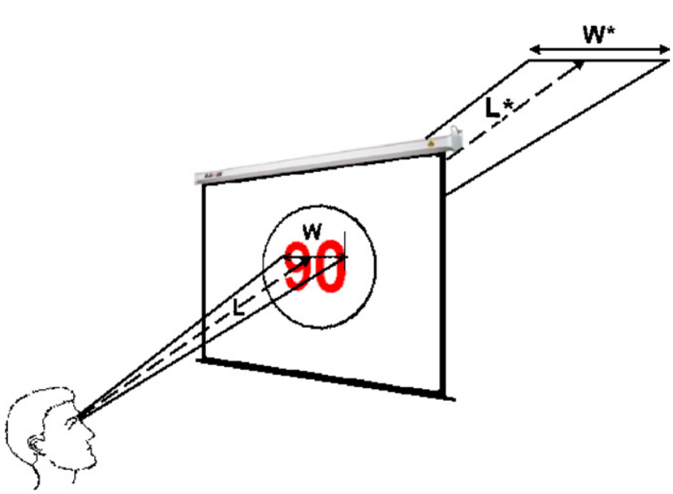

Fig. 1. Basic formula of similar triangles is used to calculate legibility distance L^*.

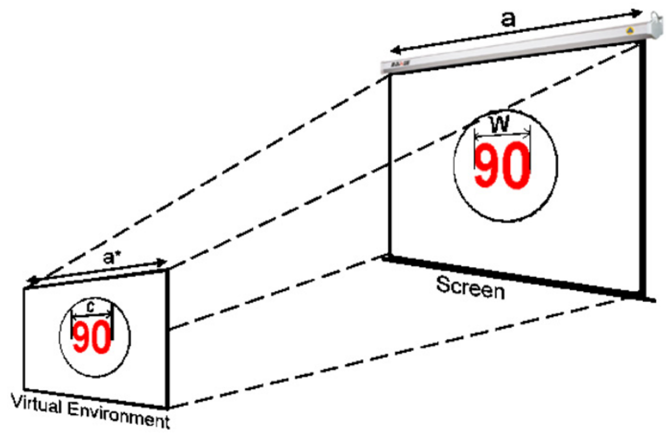

Fig. 2. Width of the virtual object shown on the screen, w, is obtained from the resolution of the virtual object.

Fig. 3. Screen image of the view of the driving environment.

2.2. Participants

Participants enrolled in this study were 30 healthy and non-disabled volunteers aged 20–30 years ($M = 22.2$, $SD = 2.19$). All had corrected visual acuity of 0.8 or better based on the Snellen scale. Each was informed of test requirements and gave formal consent to participate.

2.3. Experimental apparatus

2.3.1. Driving simulator

Experiments of traffic sign recognition were first conducted using a driving simulator. The simulator, developed by the Institute of Transportation in Taiwan, comprised a physical driving cabin, a Stewart motion platform, virtual reality-based visual and audio systems, a computer program for vehicle motion simulation, and a host computer system for simulating a lifelike driving environment. Fig. 3 presents a screen view of the driving environment.

The driving cabin is a real car body mounted on hydraulic Stewart motion platform that generates motion during driving. The platform has six degrees of freedom in roll, pitch, yaw, longitudinal, lateral and heave. The virtual environments were created using EON studio 4.0 (EON