APPLICATION OF PARALLAX FOR THE MEASUREMENT OF VISIBILITY DISTANCES IN THE OPEN ROAD ENVIRONMENT

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ABSTRACT

This paper describes a parallax technique, which was developed to assist research into the assessment of visibility and legibility of traffic signs while drivers are in the open road environment. Older drivers have a high traffic accident rate and difficulties with sign recognition have been cited as a problem. However, those studies which have investigated the sign visibility problems of older drivers have been conducted under laboratory conditions, which do not adequately reflect the dynamic complexity of the normal driving environment. Yet these are the conditions with which the elderly report the most difficulty. The technique utilised two commercially available JVC GR-DV1 digital video cameras affixed to the research vehicle. Under dynamic conditions, subjects indicated when they first recognised a given sign by activating an image identification system. This system identifies pairs of stereoscopic images which are later downloaded, and parallax values of road furniture measured. The visibility distances of signs from the moving vehicle were then determined. The method was tested in the open road over a series of predetermined reference distances and a high level of agreement was obtained between distances measured by this technique and the reference distances. The method has been used successfully for the assessment of visibility distances and this paper presents data from subjects tested under daytime and nighttime conditions. The results demonstrate that this technique based on photogrammetric principles can accurately, reliably and economically measure visibility distances of road furniture under varying driving conditions for a range of drivers.

1. INTRODUCTION

The community is aging; long term projections estimate a 100% increase in people aged 65 years and over by the year 2031 (ABS 1988). This growing population of elderly people considers driving to be a right rather than a privilege and are likely to continue to drive well into old age. This predicted increase in the number of older road users is of importance, as road users of 60 years or more have nearly a one and a half times greater chance of being killed in road accidents than adults aged 30 to 59 years (ABS 1992)

Although there is a substantial literature indicating that older drivers suffer a variety of driving difficulties and risks, the underlying reasons are not well established (Transportation Research Board 1988). However, slower time to perceive and react to roadway events has been highlighted as potentially significant (Lerner et al 1991). This is supported by evidence from accident statistics, which indicate that while accidents involving younger drivers can be attributed to speeding, reckless driving or driving when intoxicated, older drivers have accidents which most frequently involve, intersections, failure to yield the right of way, inability to turn properly or failure to heed traffic signs (Hustin and Janke 1986).

Surveys of the elderly regarding their driving experiences indicate that they have difficulty with the use of traffic signs when driving under conditions of low illumination (Yee 1985). This study also found that older drivers had problems with traffic design, traffic signs and markers. Kline et al (1992) identified eight main visual problems that older people encountered when driving; one of them was reading traffic signs quickly enough to be able to react to them. These findings suggest that at least some of the difficulties that older drivers have with traffic signs are attributable to visual problems. This is likely to be a consequence of the normal age-related changes in vision. Visual impairment arising from eye diseases such as cataracts, glaucoma and age related maculopathy also increases significantly with age. However, these changes in visual characteristics of the elderly are generally not accounted for in traditional highway design practises, including the design of traffic signs.

A limited number of studies have investigated the difficulties that older drivers experience with traffic signs. It has been reported that aging results in a significant reduction in the distance at which traffic signs can be read (Evans and Ginsburg 1985), particularly under conditions of low illumination (Sivak et al 1981). However, laboratory-based measures of visual acuity do not predict these age-related differences in traffic sign legibility (Sivak et al 1981). Recent studies have been undertaken in an attempt to investigate both the visibility (ability to see sign) and legibility (ability to read/interpret sign) of traffic signs (Babbit Kline et al 1990; Kline & Fuchs 1993; Lambert & Fluery 1994). The major flaw in these studies is that they have been conducted in the laboratory, where the subjects are not moving relative to the signs, nor are the ambient lighting conditions well matched to those of the normal driving environment. Furthermore, the normal driving environment is very complex, it includes clusters of traffic signs, advertisement hoardings, traffic lights as well as other road users. These conditions are not simulated in the laboratory studies, yet these are the situations with which the elderly report the most difficulty (Kosnik et al 1990).

This paper describes the application of a technique (Jones et al 1977) which enables the accurate measurement of visibility distances of traffic signs or other objects, while subjects are in a normal open road environment. The system was developed to meet the criteria of being economical, robust, easy to use and could be assembled from readily available commercial products.

2. METHOD

2.1 Measuring Principle

Photogrammetric principles were adopted for determining the sign visibility distances. Parallax, or the difference in the image position of an object point in a pair of stereoscopic images, is related to a number of factors including the distance from the camera to the object. The parallax increases as the distance decreases and conversely decreases as the distance increases. Thus, in principle, the visibility distance can be determined by measuring the parallax of a point in the two images.

2.2 Parallax - Visibility Distance Relationship

For the normal case, i.e., camera axes parallel and perpendicular to the base, the geometric relationship is given by:

$$\text{visibility distance} = \frac{\text{camera base} * \text{principal distance}}{\text{x parallax}}$$

(Kraus 1993)

Figure 1 shows a typical parallax-visibility distance reference graph from the current study. The reference graph was plotted from field measured distances of a centrally positioned target and the associated parallax values from the stereoscopic images taken at those distances.

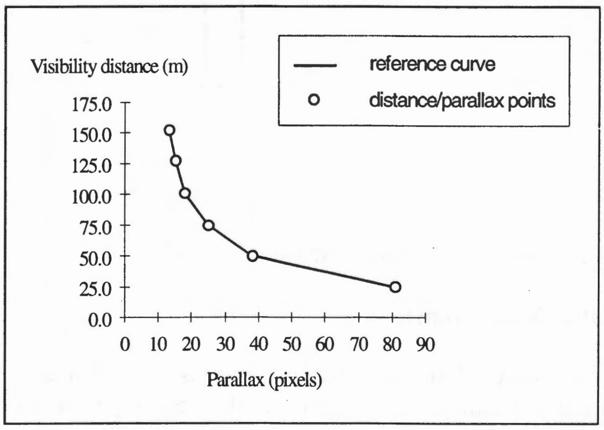

Figure 1. Parallax-visibility distance reference graph.

By plotting parallax against visibility distance the primary parameters of camera base and principal distance do not have to be determined explicitly, although their values are known through measurement and calibration. In addition, this procedure also compensates for non parallel camera axes which occur when affixing the cameras to the vehicle prior to each driving assessment.

The above process has been semi automated using spreadsheet software incorporating a least square solution. This software allows the parallax visibility distance relationship to be modelled, incorporating deviations from normal case geometry, including the effect of unmatched camera principal distances. The mathematical model was fitted to the observational data so that the sum of the squares of the weighted residuals of the image measurements was a minimum. This gives a consistent result and allows easy extraction of visibility distances from the input parallax values.

2.3 Camera System

A dynamic system was developed to accommodate a flexible approach to 'on road' driving assessment. Digital video cameras were selected as they permit continuous recording of road scenes and the sound track can be used for comment and clarification of the signs or objects that the subject views.

The system consisted of two JVC DV1 (f=4.5~45mm; image size: 768 by 522 pixels) digital video cameras. A calibration procedure was undertaken and the principal distances of the cameras were found to be approximately 1700 pixel units. The cameras were affixed on a base bar 1.435 metres apart, which was mounted on the roof of the research vehicle above the drivers' position (Figure 2) with camera axes horizontal, parallel and perpendicular to the base.

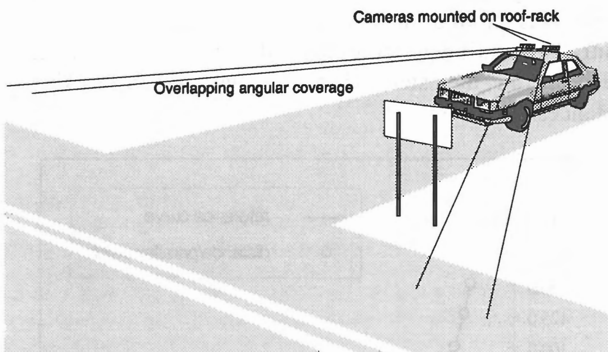

Figure 2. Research vehicle measuring system.

2.4 Predicted Accuracy

The accuracy relationship between the visibility distance and image position can be predicted theoretically from an application of the formula found in Kraus (1993). The mean-square error is given by:

$$\frac{\text{visibility distance}^2 * \text{image measuring accuracy}}{\text{principal distance} * \text{camera base}}$$

This relationship delivers the predicted accuracy of the visibility distance, and is dependent upon the sign visibility distance, the base distance between the two cameras, the principal distance of the cameras and the accuracy with which the position of the sign or target can be measured in the image. The predicted theoretical accuracy based on a measuring resolution of one pixel was calculated to be less than 10% of the visibility distances required for the project.

2.5 Image Marking System

A specially designed and built fibre optic marking system was used for synchronising and identifying stereoscopic pairs of images. The system comprised two fibre optic cables each attached to a miniature light source. These were connected to the in-car battery adaptor for power and operated by a single switch. The fibre optic cables were affixed to the front of the lens of each of the cameras. When activated by the experimenter a point source of light appeared simultaneously in each image frame thus identifying stereoscopic pairs of images.

2.6 Image Acquisition

Prior to each driver assessment the research vehicle with cameras affixed was driven over a system calibration range. The camera system was aligned with known reference marks and corresponding pairs of images identified by activating the image identification marker. A parallax–visibility distance reference graph was generated from the resulting information and used for the subsequent on-road driving assessment (an example is given in Figure 1).

The digital video system recorded pairs of stereoscopic images continuously at a rate of approximately 25 frames per second. At this data capture rate, the vehicle travels less than a metre per frame for vehicle speeds up to 80 km/hr. This cycle time between frames is not critical to the accuracy of the project. Selected stereoscopic image pairs were downloaded from the digital video cameras into a personal computer using interfacing software. Corresponding points in each of the images were measured in pixel coordinates. Parallax was deduced from these coordinates and later used to determine the visibility distances from the parallax–visibility distance reference graph.

2.7 System Validation

A series of calibration tests were carried out on the dynamic system in order to verify the accuracy of the technique. These were undertaken on the closed road circuit in the following way. Sensor switches were set up across the road at predetermined distances from a target light so that when the research vehicle passed through the sensor at a representative speed the target light was illuminated.

In each of the tests, the parallax of the target light in corresponding pairs of images was measured and the visibility distances determined from the parallax-visibility distance reference graph. The distances from the reference graph were then compared with actual field distances to validate the method. The procedure remained valid for each setup (i.e., as long as the camera system geometry remained constant). The results of the validation tests appear in Table 1.

Reference	Day		Night	
Distance (m)	difference	%	difference	%
24.9	-0.9	3.6	-2.2	8.8
50.2	-0.9	1.8	-3.3	6.6
75.4	-0.7	0.9	-0.7	0.9
101.4	+2.7	2.7	+2.7	2.7
127.0	-1.5	1.2	-1.5	1.2
153.1	-7.5	4.9	-7.5	4.9

Table 1. Differences between the measured visibility distances and the true distances in metres and as a percentage accuracy for the dynamic day and nighttime validation tests.

3. DRIVER ASSESSMENT

3.1 Characteristics of the Drivers Assessed

Three subjects were used in this preliminary study. These included a younger (27 years) and older (68 years) male with normal vision and an older male (76 years) with advanced cataracts and age related maculopathy.

3.2 Experimental Design and Driving Route

The experiment was conducted on an open road course within the boundaries of the city of Brisbane, Australia. The course comprised a number of different traffic situations and road types including inner city, highway, busy and quiet suburban roads and backstreets to test the effects of different background stimuli or noise on the recognition of street signs. Due to safety issues the subjects were passengers during the study. The length of the course was 26.5km. Subjects were seated in the front passenger seat of the vehicle and were driven around the course. They were given a set of instructions explaining what they were required to do during the experiment and also what type of signs to observe. Table 2 shows representative examples of the type of signs used. The subjects were required to press a button activating the image marking system when they could first recognise each sign and to report all of the signs that they had seen while being driven around the course. The results were scored in terms of the visibility distance and accuracy of the report. A trial run was conducted to familiarise the subjects with the requirements of the experiment.

Sign No.	Sign	Type/Size
1	(White/Black/Red) 50 speed - Regulatory	Non Reflective SMALL
2	(Green)-Text City	Retroreflective LARGE
3	(White/Black)-Text Holland Road	Retroreflective SMALL
4	(Green)-Text Margaret Street	Retroreflective LARGE

Table 2. Type of signs used for visibility distance comparisons.

3.3 Driving Conditions

The open road course included a number of different tasks such as the detection of a range of different traffic sign configurations (text and icon, direction, warning, self reflecting, self illuminating) for both low and high density road conditions. The subjects were also tested under daytime and nighttime conditions to investigate if there were any differences in sign visibility distances under different levels of illumination.

3.4 Results

Figures 3 and 4 show the results that were obtained for the subjects under varying road and environmental conditions. For the purpose of this paper, the results for only four signs are given as representative examples. It can be seen that there were differences in the visibility distances of signs for different age groups, types of signs and lighting conditions.

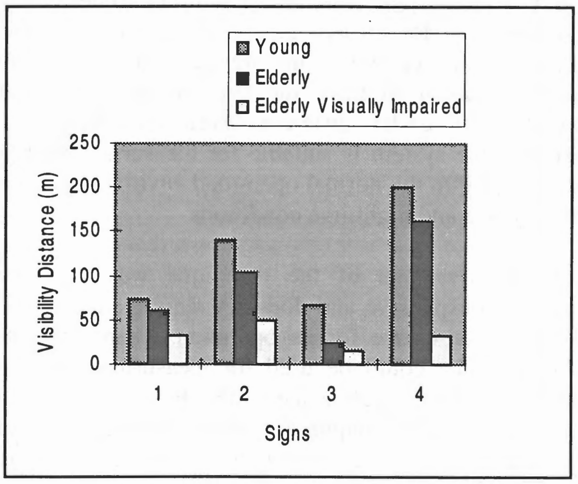

Figure 3. Visibility distances measured for a series of traffic signs under daytime conditions.

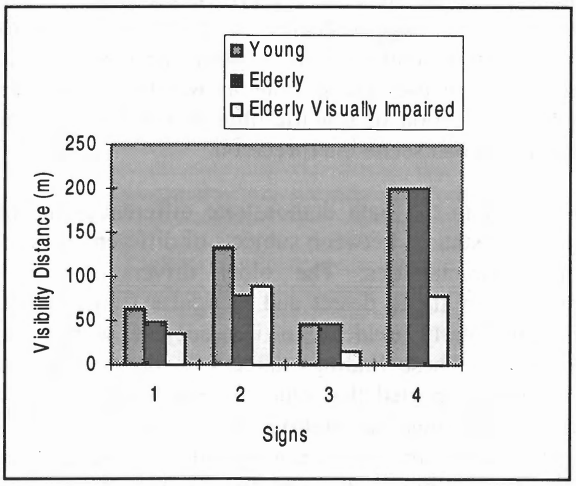

Figure 4. Visibility distances measured for a series of traffic signs under nighttime conditions.

The younger subject showed longer visibility distances compared to the elderly and the visually impaired elderly subject for both daytime and nighttime conditions. The visually normal elderly subject generally showed longer visibility distances than the visually impaired elderly subject. All subjects had longer visibility distances during daytime conditions, than for nighttime. Sign 4 showed an increased visibility distance under low illumination due to its relatively large size and use of high level retroreflective material. When signs 2 and 4 are compared it can be seen that sign 2 had decreased visibility distances compared to sign 4 due to the location and positioning of the signs.

4. DISCUSSION

The findings demonstrated that the technique can accurately measure sign visibility distances under 'on road' conditions. The technique was found to be accurate to within 10% for all distances tested, and this is well within the requirements of the present study. The system was also shown to have the capacity to make these measurements under different levels of illumination. Therefore the system is suitable for measuring visibility distances within the normal open road environment under both daytime and nighttime conditions.

A major advantage of the technique was that it is relatively inexpensive and does not require sophisticated or complex software for its operation. There are other techniques that could be used for measuring road sign visibility distances such as the Global Positioning System (GPS) and mobile mapping systems (Bossler & Toth 1996). However, these systems are relatively expensive and normally require skilled operators and the use of external software systems for data retrieval and processing.

Studies by Burie et al (1995) have outlined a mobile system based on stereoscopic principles, which can be used for detecting obstacles in front of a vehicle. However, in its current form it would be unsuitable for this study as it uses linear cameras which are optimised for rapid detection of specific objects and which do not provide for road scene interpretation.

The trends in the data demonstrate differences in sign visibility distances between subjects of different ages and visual characteristics. The older drivers showed a decreased ability to detect and recognise signs and this was particularly evident in the subject with visual impairment. These findings agree with previous studies which have reported that older drivers have difficulties with traffic signs recognition (Yee 1985, Kline et al 1992). The decrease in sign visibility distance under nighttime conditions observed for all subjects was also consistent with the fact that visual discrimination becomes worse under reduced illumination levels. The reduction in sign visibility distance under nighttime conditions was greatest for the cataract subject. This finding is likely to arise as a result of the increase in glare and light scatter caused by the opacity of the lens of the eye. Again this confirms previous studies which have shown that the elderly have greater difficulty with driving under decreased illumination (Yee 1985).

Some of the signs did show an increase in their visibility distance under nighttime conditions. This is likely to be because these signs contained retroreflective materials, which increase sign visibility at night. There were also differences seen in the visibility distances between the different signs. Variations in the size, colour and shape all contribute to the differences found. This was evident for signs 2 and 4, which showed greater visibility distances than signs 1 and 3 for all subjects. This is because both were very large highway signs and contained reflective tape materials, making them highly visible under both day and particularly night conditions. Further detailed studies with larger subject sample sizes will yield more meaningful information on the differences in the visibility distance of signs for different age groups and visually impaired subjects under both daytime and nighttime conditions. Another contributor to differences in sign visibility distances is the position of the sign relative to the driver and the road and any other objects obscuring the sign from the driver's field of view. This was evident in the results obtained for signs 2 and 4, which showed that in general, sign 2 had decreased visibility distances compared to sign 4. This is likely to be due to the fact that sign 2 was slightly obscured by trees and other objects on the side of the road and was also on a short stretch of straight road. Sign 4 however, was on a very long straight stretch of road with nothing to obstruct its field of view.

In summary, the system described in this paper is an important tool that can be used by the visual scientist for the measurement of true visibility distances of traffic signs and road objects within the open road environment. Studies are currently being undertaken to investigate how the age and visual characteristics of a driver affects the perception and recognition of traffic signs in a normal driving environment and how this can be affected by different road and environmental conditions. This information will form the basis for recommendations on improving traffic sign designs to accommodate the needs of all road users including the elderly and those with visual impairment.

5. CONCLUSIONS

The system described in this paper provides a means of measuring sign visibility distances within the open road. In addition, it has the facility to produce a three dimensional image of the road scene which permits detailed analysis of other factors present within the context of the on-road environment. This real environment involves many different visual distracters including advertisement hoardings, clusters of traffic signs, traffic lights and other road users which contribute to the problems which the elderly experience whilst driving a vehicle on the open road. The pilot data obtained with the system, demonstrated differences in the sign visibility distances of subjects of different ages and visual characteristics; factors such as illumination and sign characteristics were also important.

The technique also fulfils the required criteria of being accurate, easy to use and economical. It can be assembled from readily available components, provides a permanent visual record of the experiment and is able to measure sign visibility distances under 'on road' conditions under different illumination levels and for a range of drivers.

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