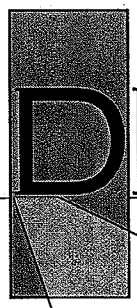


Innovations Deserving
Exploratory Analysis Programs

Highway Program

Automated Mobile Highway Sign Retroreflectivity Measurement

Final Report for Highway-IDEA Project 75

Norbert H. Maerz and Qiang Niu,
University of Missouri-Rolla

February 2003

TRANSPORTATION RESEARCH BOARD • THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This NCHRP-IDEA investigation was completed as part of the National Cooperative Highway Research Program (NCHRP). The NCHRP-IDEA program is one of the four IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in highway and intermodal surface transportation systems. The other three IDEA program areas are Transit-IDEA, which focuses on products and results for transit practice, in support of the Transit Cooperative Research Program (TCRP), Safety-IDEA, which focuses on motor carrier safety practice, in support of the Federal Motor Carrier Safety Administration and Federal Railroad Administration, and High Speed Rail-IDEA (HSR), which focuses on products and results for high speed rail practice, in support of the Federal Railroad Administration. The four IDEA program areas are integrated to promote the development and testing of nontraditional and innovative concepts, methods, and technologies for surface transportation systems.

For information on the IDEA Program contact IDEA Program, Transportation Research Board, 500 5th Street, N.W., Washington, D.C. 20001 (phone: 202/334-1461, fax: 202/334-3471, http://www.nationalacademies.org/trb/idea)

The project that is the subject of this contractor-authored report was a part of the Innovations Deserving Exploratory Analysis (IDEA) Programs, which are managed by the Transportation Research Board (TRB) with the approval of the Governing Board of the National Research Council. The members of the oversight committee that monitored the project and reviewed the report were chosen for their special competencies and with regard for appropriate balance. The views expressed in this report are those of the contractor who conducted the investigation documented in this report and do not necessarily reflect those of the Transportation Research Board, the National Research Council, or the sponsors of the IDEA Programs. This document has not been edited by TRB.

The Transportation Research Board of the National Academies, the National Research Council, and the organizations that sponsor the IDEA Programs do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the investigation.

ACKNOWLEGEMENTS

We would like to thank the National Cooperative Highway Research IDEA Program for its funding of this project. We would also like thank the Missouri Department of Highways (MODOT) for their help, providing signs, a portable retroreflectometer, and technical assistance and advice. Thanks to Larry Thompson from the MODOT sign shop, Jim Brocksmith, Tricia Alberts, and Audi Pulliam from Traffic Engineering, and Ray Purvis, Daniel Smith, and Don Davidson from Research, Development and Technology.

TABLE OF CONTENTS

Acknowlegements 2

Table of Contents 3

Executive Summary 4

1. IDEA Product, Concept, and Innovation 6

1.1 Background: The Purpose Of Highway Signs 6

1.2 Objectives 6

1.3 Previous Work 6

1.4 Mobile Image Based Measuring System 6

2. Investigation and Plans For Implementation 11

2.1 Overview 11

2.2 Static Studies 11

2.3 Dynamic Studies 14

3. Conclusions 15

4. References 15

Appendix 1: Retroreflectivity* Measurements 18

Appendix 2: Static Brightness* Measurements 19

Appendix 3: Test Sign Images and Correlation Between Retroreflectivity and Brightness 20

Yellow (yield) signs 20

White (speed) signs 21

Orange (construction signs) 22

Red (stop) signs 23

Yield signs 24

Blue (service) signs 25

Brown (public use) signs 25

Green (city) signs 27

Appendix 4: Reproducibility Studies 28

Bright colors 28

Specific colors 31

Appendix 5: Typical HTML Data output file 33

EXECUTIVE SUMMARY

Highway signs, which are used to promote highway safety and efficiency, need to command attention and give adequate time for driver response (*1*). At nighttime, the visibility of the signs depends on the retroreflectivity of the sheeting material on the signs. The retroreflectivity is a measure of the amount of light emanating from vehicle headlamps that is reflected directly back, by the sign, to the driver of the vehicle (figure 1).

The current practice for ensuring that the signs are performing at night as required consists of either visual inspection, measurement of retroreflectivity with a hand-held retroreflectometer, or systematic periodic replacement of signs irregardless of whether they are deficient or not. None of these approaches are ideal. Visual inspection is too subjective, hand-held retroreflectometer measurements are tedious, time-consuming, and sometimes dangerous, and systematic replacement is not cost effective.

This report describes a prototype of a digital video image analysis system that measures the brightness of highway signs using nighttime video images taken by a camera mounted in a moving vehicle.

The *concept* is that by using an inexpensive video camera and laptop computer mounted in a vehicle (figure 2), a measurement of the brightness and visibility of the sign can be made. The system uses real time image analysis of night images of signs acquired on a mobile platform moving at highway speeds, illuminated by normal vehicle head lamps. Using video images at night results in measurements that as closely as possible reflect what the human eye sees.

The *innovation* is in using state of the art video imaging hardware and designing real time image analyzing software to identify and measure the brightness of the sign in real time from live video images (as the vehicle travels along the roadway) or from recorded digital video images. The video hardware uses high speed IEEE 1394 ("firewire", "i.LINK") connectivity to bring digital images from the camera to the computer in real time. The purpose designed video software (figure 3) analyzes images by first identifying the sign, classifying the type of sign, measuring the brightness of the sign, and determining if it meets minimum standards. Each sign is measured multiple times as the vehicle moves down the highway. The maximum measurement is taken and recorded in a data file, along with the time and a thumbnail image of the sign. Future enhancements will add GPS coordinates or mileage reference to the data file

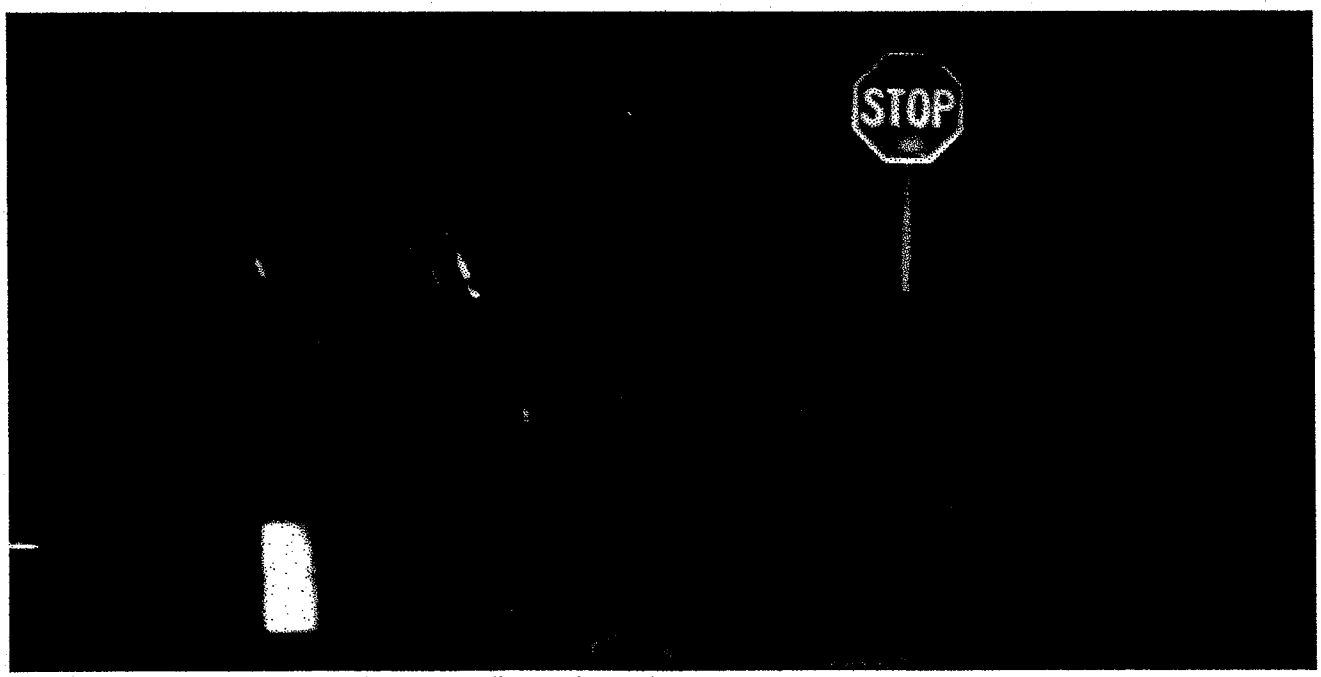


FIGURE 1. Stop sign illuminated by headlights of a vehicle.

The goals of this project were to prove the concept and develop a prototype that could identify signs by color and measure the retroreflectivity at a given measured distance for signs that are relatively isolated. These goals were achieved with two modifications. Brightness is measured rather than retroreflectivity, and instead of measuring at a given distance, the signs are measured continuously, and the largest measurement is retained.

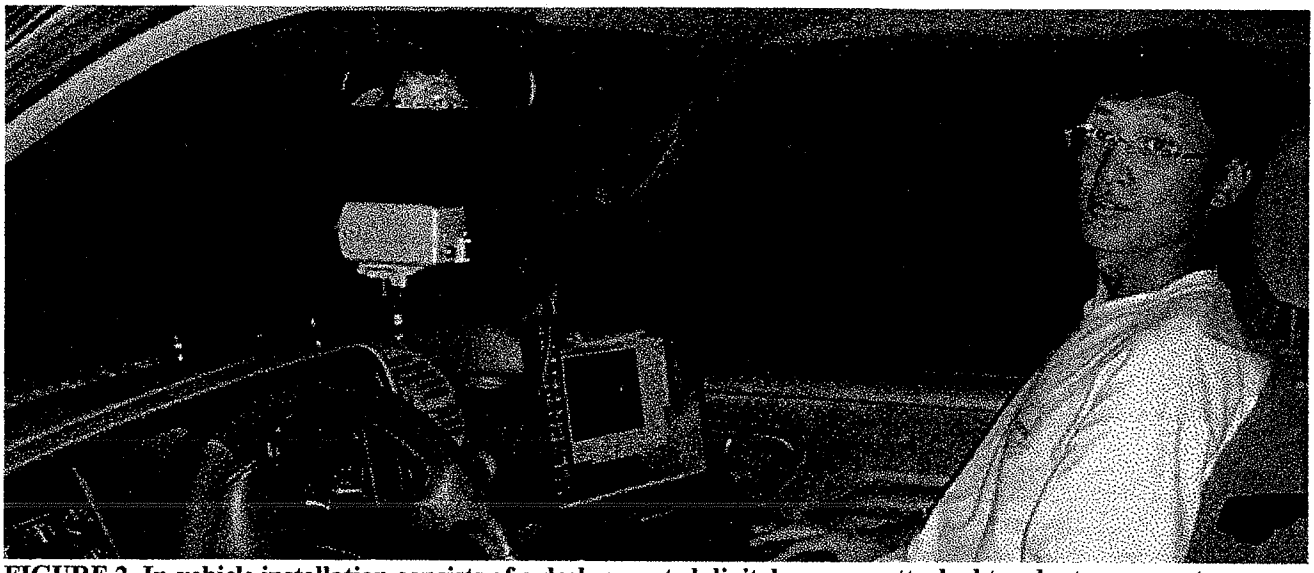


FIGURE 2. In-vehicle installation consists of a dash mounted digital camera, attached to a laptop computer.

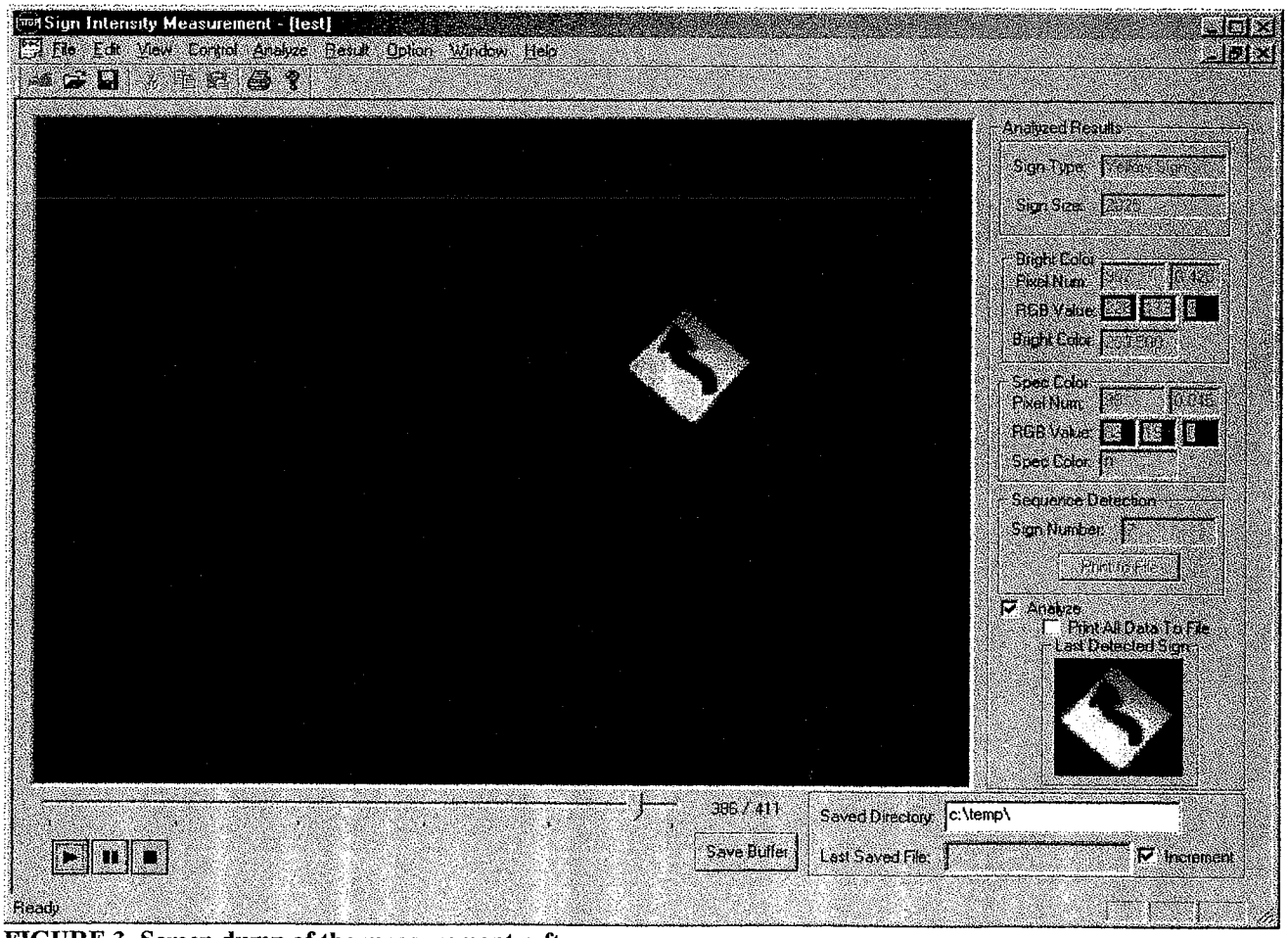


FIGURE 3. Screen dump of the measurement software.

Results of this research have not only demonstrated that this is a viable way to evaluate the effectiveness of the signs at night, but research has also shown that the retroreflectivity of signs as measured by portable retroreflectometers is not well correlated with the visibility of the signs.

1. IDEA PRODUCT, CONCEPT, AND INNOVATION

1.1 BACKGROUND: THE PURPOSE OF HIGHWAY SIGNS

Highway signs serve the purpose of communicating to the motoring public the information they require for guidance and direction and to warn them about upcoming hazards. When properly informed the drivers can focus their attention on safely controlling their vehicle, and not on wondering where the next exit might be or whether they are on the correct road. When informed of upcoming hazards, drivers can reduce their speed and increase their awareness, and be confident to resume their normal speeds to keep traffic moving in the absence of hazards. In all, a well-informed driver will be more comfortable, less stressed, and less likely to make mistakes or poor judgments that could potentially cause vehicle crashes.

In the daytime signs are typically well illuminated by ambient light, and assuming correct placement, are generally easy to read. At nighttime the situation is quite different. The only source of light is likely to be emanating from the headlamps of the driven vehicle itself, and the only way that the sign can be seen from an appropriate distance is if the sign is retroreflective (Fig. 1). (Retroreflected light is light that is reflected back in the exact direction from whence it came.) Inadequate or deteriorated signs are difficult to read at night, especially for older drivers, and this is thought to contribute to crashes, injuries, and fatalities.

The current version of the Manual on Uniform Control Devices (MUTCD) (1) specifies that warning and guide signs must be made retroreflective, but does not yet specify minimum retroreflectivity standards. In response to a 1993 US congressional directive, (Congress has mandated that the Federal Highway Administration (FHWA) must develop "a standard for a minimum level of retroreflectivity that must be maintained for...signs..." the Federal Highway Administration is evaluating and helping develop instruments and tools to measure retroreflectivity and will in time be modifying the MUTCD to institute retroreflectivity standards for signs, much like as has been done for pavement stripes.

1.2 OBJECTIVES

The objective of this project is to demonstrate that the nighttime visibility of highway signs can be measured using imaging analyzing software, imaging equipment, and vehicle headlamps as an illumination source, and to build an inexpensive prototype of a mobile real time system that can accomplish this task, using off the shelf hardware. This approach is better than current technologies, which consist of hand-held measurement devices that are not capable of analyzing large numbers of signs, nor of measuring average values over physical extent of a sign. This approach will also have significant advantages over an FHWA mobile measurement device under development, which requires a laser range finder, a second operator, and electronic strobes, and results in significantly higher capital and maintenance costs.

1.3 PREVIOUS WORK

A literature review has revealed a small body of work with regard to sign recognition, standards, and testing. A significant number of papers deal with automated sign recognition (2-18) under daylight conditions. A significant number of papers deal with sign retroreflectivity standards, visual evaluations, and seeing distance (19-26). A single paper proposes a mobile system (27). A prototype of a mobile system is described on FHWA web sites (28-30). Previous work by this author in mobile measuring systems include laser-based pavement stripe retroreflectivity (31) and mobile imaging of highway features for inventorying (32).

1.4 MOBILE IMAGE BASED MEASURING SYSTEM

The sign measurement system described herein was designed as a low cost system to be mounted in any vehicle, using nighttime images of signs illuminated by vehicle headlamps, thus making measurements that as best as possible reflect what the human eye can see. The system uses inexpensive, state of the art, off the shelf hardware to acquire the images. Purpose designed software acquires, classifies, and analyzes the brightness of the images in real time, and reports results to a data file.

1.4.1 Hardware

The system makes use of a color digital video camera, a laptop computer, and a high speed IEEE 1394 ("firewire", "i.LINK") connectivity to bring digital images from the camera to the computer in real time.

The laptop computer is a Sony Vaio, chosen because it was the only laptop brand fully able to support firewire imaging.

A Sony DFW-V500 firewire camera is a YUV- 422 camera that contains lookup tables (as do most cameras) to render colors the way they appear to the human eye. Being a fire wire camera, it can input directly into the laptop

computer without the need for image capturing devices. The camera is a 1/3" color CCD camera using a 25 mm lens with a maximum aperture of F1.4.

Figure 1 shows the camera and laptop computer as it is installed and used in the vehicle. A makeshift mounting bracket with a ball head holds the camera in place at a fixed angle to the path of the vehicle.

1.4.2 Software Components

1.4.2.1 Overview

Software development was considered to be the most important development for this application. Microsoft Foundation Classes® (MFC) under 32 bit Microsoft Windows® Operating System (WIN32) were used. C++ was used as the development language and DirectShow® and COM® (Component Object Model) as the core API's. Image-processing algorithms were developed in-house, and integrated under Microsoft Visual C++® environment.

1.4.2.2 Direct Show

Microsoft DirectShow is architecture for streaming media on the Microsoft Windows platform. DirectShow is the successor to Microsoft Video for Windows and Microsoft Active Movie, and it improves on these older technologies in significant ways. It is based on Microsoft's Component Object Model (COM) architecture and is part of DirectX®.

DirectShow is an application programming interface (API) for client-side video and image processing. It offers three core features and all of them are used in this application:

1. Video capture,
2. Video playback,
3. Multimedia streaming.

1.4.2.3 Video Capture

Video capture is the process of acquiring a digital video image. With the capture graph and capture filter supplied by DirectShow, and Microsoft Windows Driver Model® (WDM), Microsoft provides a powerful software environment for developers to build portable image applications almost independent of internal/external devices, so we can preview live video, capture live video as AVI (Audio Video Interleave) file, save the buffer of the live video as a BMP file, using captured data to do real time analysis, etc.

With WDM drivers, the camera manufacturer is responsible for providing the interface to the camera. All the relevant camera settings including brightness, contrast, hue, saturation, sharpness, gamma, white balance, and backlight compensation (which is actually shutter speed) can be set, and most importantly, any automatic settings can be disabled (Figure 4). This is critical to producing reproducible measurements, and eliminates the need for continual calibration.

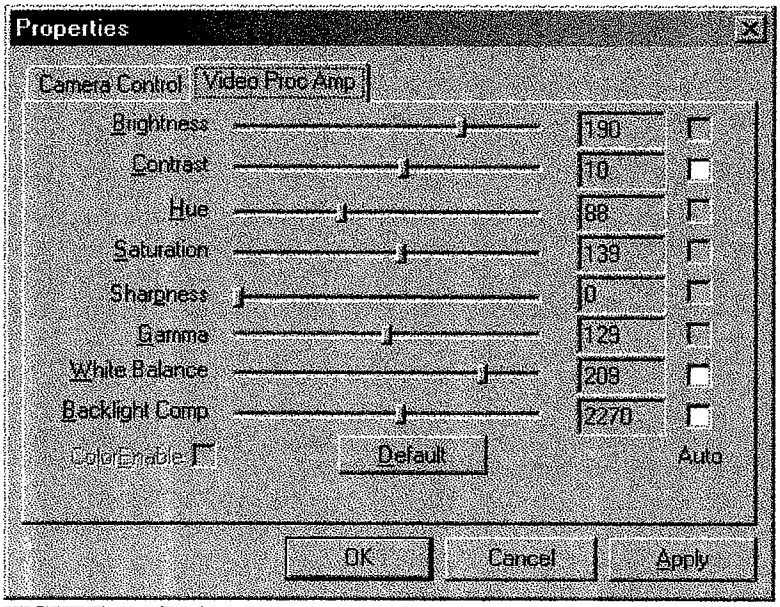


FIGURE 4. Setting parameters using the video capture filter.

1.4.2.4 Image Analysis

In order to measure the signs, the individual signs must be isolated, classified, and measured, and the data must be stored in a meaningful way.

Sign Isolation

Each image, while in the frame buffer, is checked for the substantial presence of a sign. The method used is a region growing algorithm, based on the vector angle color similarity measure and the use of the principal component of the covariance matrix as the "characteristic" color of the region, with the goal of a region-based segmentation which is perceptually-based.

Sign Classification

From the Manual on Uniform Traffic Control Devices (MUTCD) (33), there are in total 7 kinds of signs by colors: blue, brown, green, orange, red, yellow, and white, so the target sign is identified in terms of colors. These were used both for the classification and measurement.

These colors divide into three groups:

1. The "dull" (nominally black, nominally zero retroreflectivity) color is where each of the Red, Green, and Blue (R, G, B) buffer values are all less than 50 (on a scale of 255). These values are considered so low that they cannot be effectively measured.
2. The "bright" color consists of white, yellow, or orange, which are the highly retroreflective colors. These are defined by R, G, and B values all greater than 50.
3. The "specific" color consists of red, green, blue, or brown which are the lower retroreflectivity colors. These are defined by all any combination of R, G, B values where at least one is above 50 and another below 50.

The actual classification of the sign is determined by the intensity of the red, green, and blue (R,G,B) values, and the ratios of these values, in the following algorithm:

If the total percentage of the specific color is < 10% of the sign area:

If the bright color's $R \approx G \approx B$ and the specific color's $R \approx G \approx B$, then it is white sign;
Else if the bright color's $R \approx G >> B$ (R/B>3), it is a yellow sign;
Else it is orange sign;

Else

If the specific color's R >> (B & G) and R>75, it is red sign,
Else if the specific color's B >> (R & G) and B>75, it is blue sign,
Else if the specific color's G >> (R & B) and G>75, it is green sign,
Else it is brown sign.

Sign Intensity Measurement

The intensity or brightness is simply the measure of the value of one or more of the R,G,B buffers:

Color	**Criteria**
White	Average of R, G, B buffers
Yellow	Average of R, G buffers
Orange	Average of R, G buffers
Red	R buffer
Green	G buffer
Blue	B buffer
Brown	Average of the R, G, B buffer

Data Storage

In order to store the results of the analysis, including real time video analysis, analysis of stored AVI files, stored bitmaps files results, or individual still frames extracted from AVI files, the identical file structure is used to create a data storage subsystem. The analyzed data can be saved as plain text (*.txt) file which can be used for database analysis, but the data

can also can be saved in hypertext markup language (*.html) file which can be used in a web browser. The target signs, which are saved as small JPEG files, are displayed in the html files as embedded images (Appendix 5).

1.4.3 User Interface

1.4.3.1 Overview

In this application, there are three analysis modes, allowing analysis from live streaming video, recorded video (AVI files) and static images (BMP files), and a fourth mode to display the analyzed results.

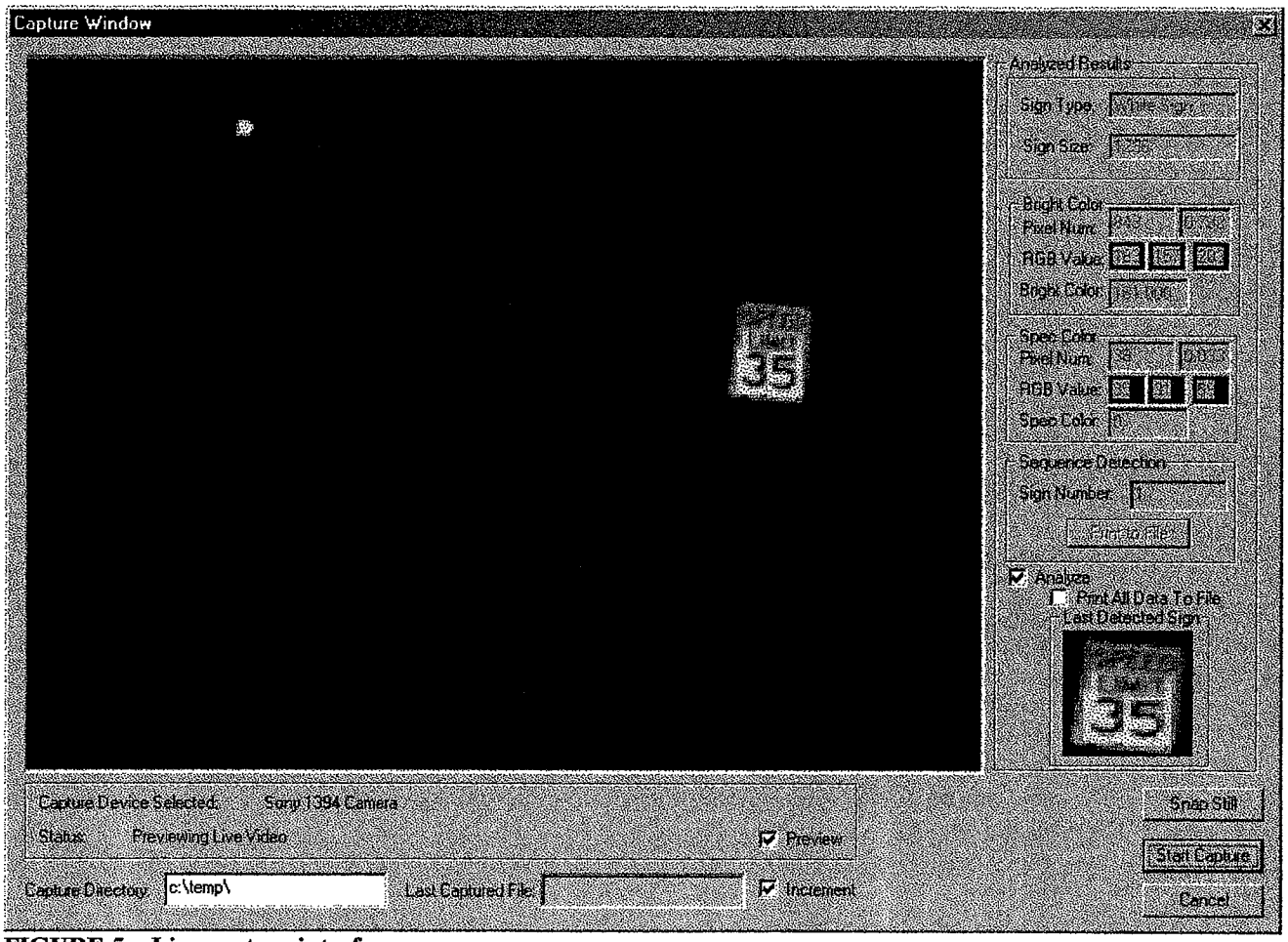


FIGURE 5. Live capture interface.

1.4.3.2 Live streaming video

Figure 5 shows the analysis interface for live streaming video, as well as the capture interface:

1. The video window shows a "live" image, if the *Preview* box is checked.
2. The capture directory can be set for storing AVI or BMP files. AVI capture is initiated by the *Start Capture* button, while BMP files are snapped by the *Snap Still* button. File names are incremented at each capture event if the *Increment* box is checked.
3. If the *Analyze* box is checked, the live video images are analyzed. Each time a sign is detected, results are displayed on the screen, including: sign type, sign size (in pixels), bright color (number of pixels, bright color percentage, average R, G, B values, and bright color value), specific color (number of pixels, specific color percentage, average R, G, B values, specific color value), sequence detection result (detected sign number), and a thumbnail image of the current (or previously) detected sign is displayed..
4. If *Print All Data To File* is checked, analyzed results are output to a text file on disk, and thumbnail images are stored on disk.

1.4.3.3 Pre-recorded AVI video

Figure 3 shows the analysis interface for AVI files. It is similar to the live streaming video, with the following differences:

1. The AVI file can be played and controlled. Using 3 buttons (Play, Pause and Stop), or the slider bar the AVI file can be played and positioned. The current frame number is displayed with the total number of frames in the sequence.
2. *Save Buffer* results in the current image being saved as a BMP disk file.
3. *Print All Data To File* results in each analysis (each detected frame, which would typically include multiple views of the same sign) being written to disk. Otherwise only the highest measured value of an individual sign is recorded.

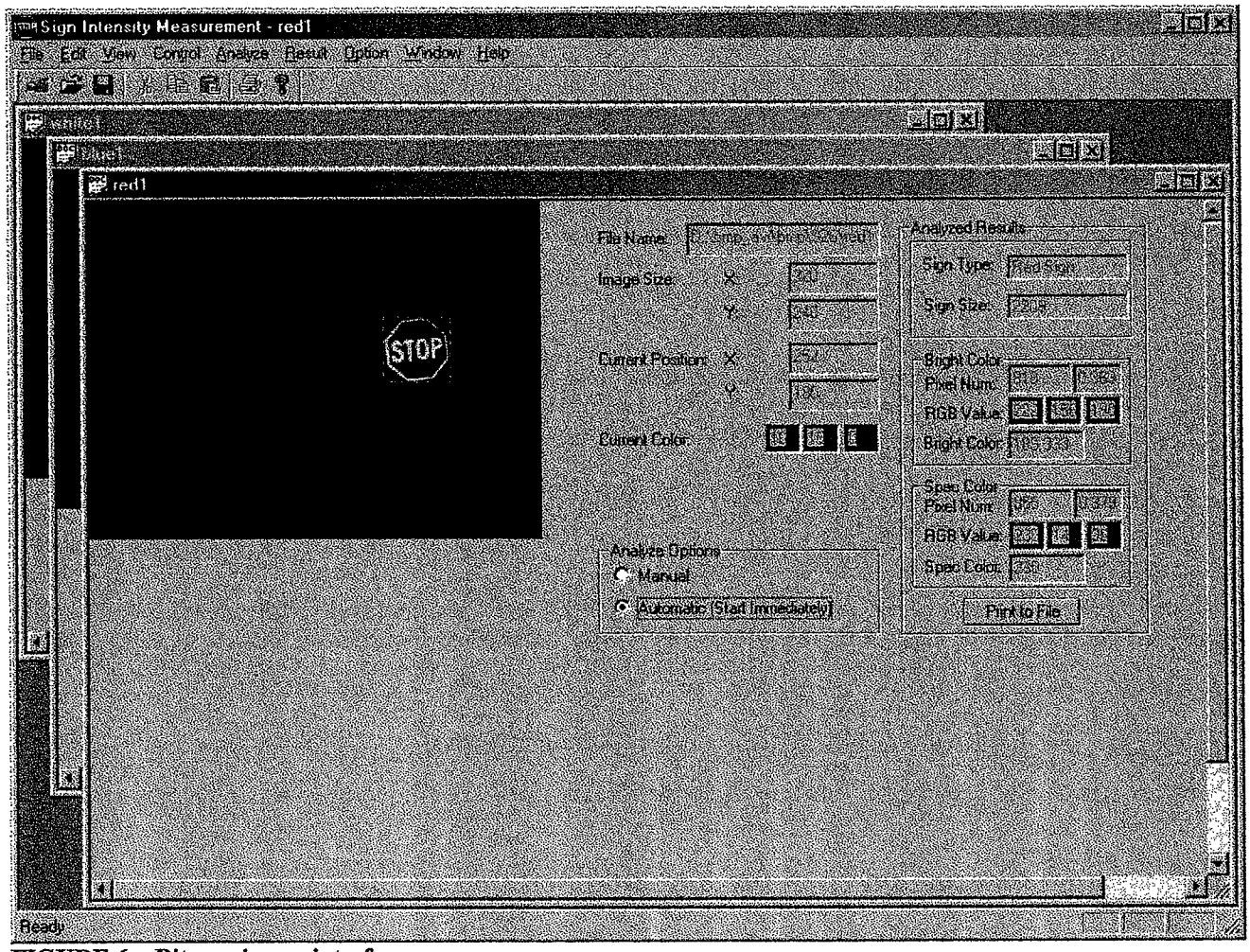


FIGURE 6. Bitmap image interface

1.4.3.4 Static BMP images

Figure 6 shows the analysis interface for BMP images.

1. The *Analyzed Results* are the same as in the other interfaces. *Print to File* allows saving of analysis results.
2. *Analyze Options* allows *Manual* and *Automatic* isolation of the sign. Automatic sign detection prints a green dashed box around the sign. Alternatively the user can use the mouse to draw a rectangle to manually isolate the sign.
3. Image properties are displayed on the screen, such as *File Name* and *Image Size*. When the cursor is passed over the image, the *Current Position* and *Current Color* values are displayed.

1.4.4 Capabilities and Limitations

This methodology is capable of measuring the brightness of highway traffic signs using the vehicle's own headlamps, and a vision system that most closely represent what the human eye can see, including receiving poor measurement results from signs with good retroreflective materials but situated where the geometry is poor, as for examples on inside horizontal curves. The measurement is done in real time at highway speeds, and produces a record that includes a small thumbnail image of the sign as well as the measurement data, and could easily be tied to GPS position information.

Limitation of the method includes the necessity of making measurements at nighttime, and the fact that measurements are more efficient using high-beam illumination, which is more disruptive to traffic. A current limitation, which could be overcome with further development, is the necessity for having relatively isolated signs with limited extraneous noise in the image. Further research will be needed to measure in noisy highway scenes, including tracking multiple signs in the same sequence of images, identifying and rejecting light sources that are not signs, and separating signs that are touching or partially overlapped.

1.4.5 Potential Impact

The potential impact of this technology is great. It will provide the tool to effectively measure the retroreflectivity of signs at a lower cost, thus allowing better-informed management decisions on which signs need replacing. This will result in safer highways, and more contented and less stressed drivers.

Given that manual hand-held measuring devices by their very nature are limited in the number of signs they can measure in a given time, and the labor (and cost) intensive nature of the process, this new measurement tool will allow more signs to be measured at a lower unit cost, as well as multiple measurements being made on each sign, to increase the statistical reliability of the measurement.

The ease and simplicity of this new analysis will result in:

1. More reliable test results.
2. More testing, resulting in better and more statistically valid characterization.
3. Faster measurements, allowing a greater proportion of the sign inventory to be checked in a given cycle.
4. Lower unit costs per measurement sample, resulting in less of a burden on operators.

2. INVESTIGATION AND PLANS FOR IMPLEMENTATION

2.1 OVERVIEW

The investigation consisted of two phases, static testing of signs to determine the relationship between the measured brightness of the signs with retroreflectivity and dynamic testing to evaluate the feasibility of measuring on the road.

2.2 STATIC STUDIES

2.2.1 Signs

The signs used for this investigation were provided by the Missouri DOT (32 different signs in all). These were:

1. Yellow (curve), 4 signs,
2. White (speed), 6 signs,
3. Red (stop), 4 signs,
4. Yield (red and white), 4 signs,
5. Blue (service), 3 signs,
6. Brown (public use), 4 signs,
7. Green (towns), 4 signs,
8. Orange (construction) 3 signs.

Each sign nominally had 4 replicates, in each of the following categories.

1. New sign with high grade sheeting,
2. New sign with engineer grade sheeting,
3. Sign taken out of service for the purpose of this project, intermediately worn.
4. Sign taken from the scrap pile, completely worn.

The signs were measured for retroreflectivity, using a Delta RetroSign Type 4500 Retroreflectometer provided by the Missouri DOT (Appendix 1). In each case the category 3 and 4 signs were hand picked to provide a complete range of retroreflectivities.

For the blue and orange signs, only three were used, as it was difficult to find specific values for the signs. For the white signs, two additional signs were added, to cover the range of low retroreflectivity.

2.2.2 Vehicle Modifications

The vehicle halogen headlamps were replaced with brighter Xenon lamps. A camera mount was fabricated on the front dash of the vehicle (Figure 2), with the camera location slightly to the left and down from the point of observation of the driver, to preserve as best as possible the observation angle of the driver while avoiding interfering with the drivers vision.

2.2.3 Static Testing Range

A measuring range was set up to facilitate the static measurements. This was an outdoor range with interchangeable signs mounted on a sign post (Figure 1). The top of the sign was set to 8' high. The signs were mounted one at a time in order to preserve the entrance angle. The distance from the headlamps to the sign was set to 120' and the distance from the sign to the camera to 125'. The entrance angle was kept constant for a set of measurements, but no effort was made to keep the same entrance angle for a repeat set of measurements, as that can be expected to vary widely under normal driver conditions. This range can of course only be used at night, and this is considered to be the most realistic approach.

In repeat testing the vehicles were positioned at the same point, but no effort was made to retain exactly the same alignment. Systematic differences do occur as a result of small changes in vehicle alignment.

2.2.4Results of Static Testing

2.2.4.1 Relationship Between Measured Brightness and Retroreflectivity

The relationship between the measured brightness of the signs and the retroreflectivity was determined by tests on the static range. Appendix 2 shows the results of the series of measurements. Appendix 3 shows the signs and the relationship between retroreflectivity and measured brightness. Appendix 4 shows the relationship for all the measurements.

As shown in Appendix 3 and 4, retroreflectivity and brightness can be correlated, but only within the same color. The "bright colors" orange, yellow and white show high retroreflectivity, and large variability in retroreflectivity but small changes in brightness, i.e. visibility is not very sensitive to retroreflectivity. The "dull colors", red, green, blue, and brown show a low retroreflectivity, with low variability in retroreflectivity, but large changes in brightness, i.e. visibility is very sensitive to retroreflectivity.

Yellow

Yellow colors are in general very bright, and visibility not highly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 25 cd/m.m.lux will appear fairly bright.

White

White colors are in general very bright, and visibility not highly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 50 cd/m.m.lux will appear fairly bright.

Orange

Orange colors are similar to yellow, in general fairly bright, and visibility is weakly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 50 cd/m.m.lux will appear fairly bright.

Red

Red colors are generally fairly bright, and visibility is strongly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of 0 appears dim, and up to 50 cd/m.m.lux will appears fairly bright.

Blue

Blue colors are generally fairly bright, and weakly correlated with retroreflectivity. All three of our signs had high visibility but low (<25 cd/m.m.lux) retroreflectivity.

Brown

Brown colors are not bright and have low visibility, as well as low retroreflectivity.

Green

Green colors are moderately bright, and visibility is weakly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of > 25 cd/m.m.lux appears moderately bright, and no retroreflectivities greater that 25 cd/m.m.lux were found.

2.2.4.2 Reproducibility

Appendix 4 shows the results of imaging the same series of signs on six different occasions. Reproducibility is fairly good, and the differences are in general systematic, as a result of setting up with a slightly different geometry for each measurement. Each series of tests were conducted with slightly different vehicle positions, resulting in different angles of illumination of the signs. Using differing vehicle positions is considered appropriate, because this will be the case when a vehicle is running down the road.

All but one of the series of measurements were done using the vehicle high-beams.

2.2.4.3 High Beam Analysis vs. Low Beam Analysis

To make measurements using low beams requires modifications to the camera setup. To accommodate this, the lens aperture was opened from f4 to f2, and changes were also made to the internal camera setting to increase amplification. The results of using the low beam are a significantly higher signal to noise ratio, and also a less even illumination of the sign (Figure 7). This is even more critical in a noisy background, where the sign is not even recognizable under low beam conditions (Figure 8).

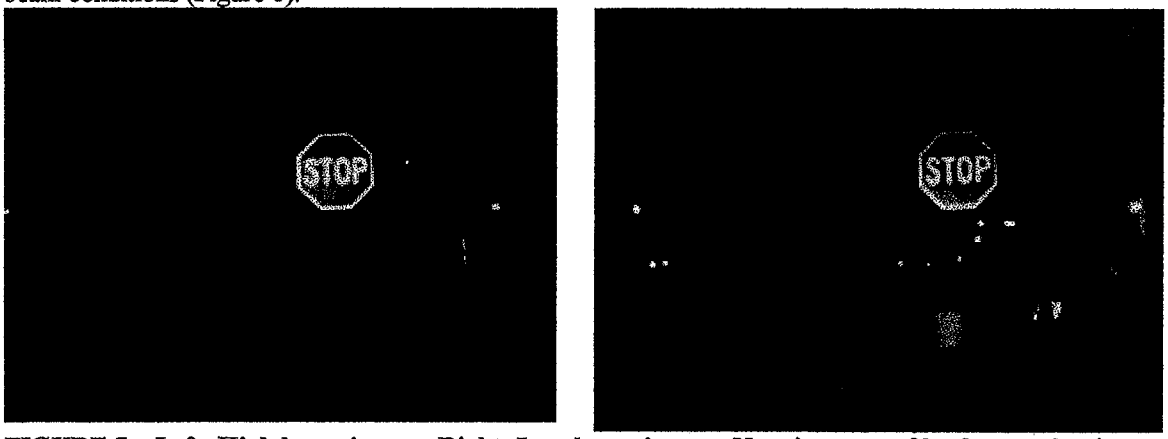


FIGURE 7. Left: High beam image. Right: Low beam image. Note increase of background noise.

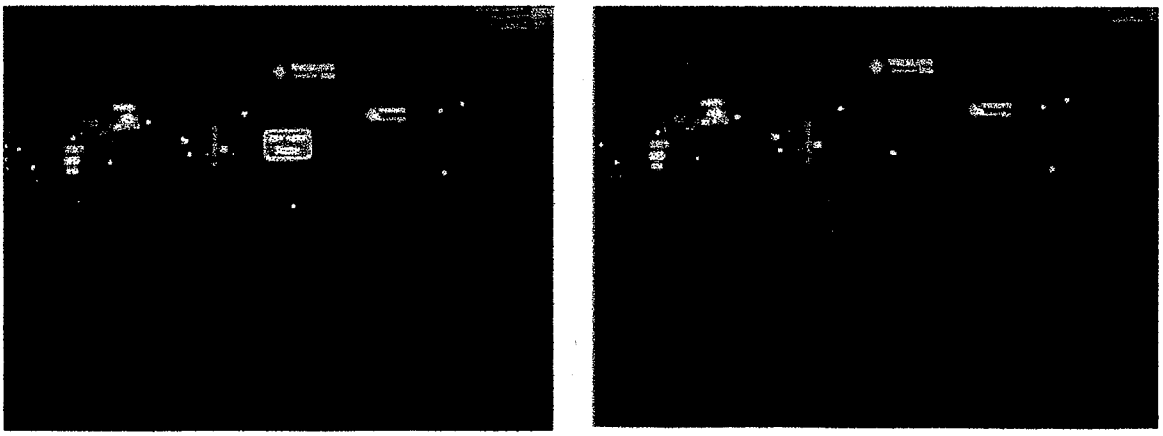


FIGURE 8. Left: High beam image. Right: Low beam image. Note that the green sign in the left image almost completely disappears in the cluttered background of "lit" signs

Visibility Standards

It is not the purpose of this investigation to set visibility standards, however it would not be difficult to select a threshold intensity value from the results of Appendix 4. These standards may have to be different for each color, and will require careful calibration of the system to maintain consistency

2.3 DYNAMIC STUDIES

2.3.1 Overview

Dynamic studies were done to demonstrate the measurement in real time and from moving AVI files, and also to reconcile the issue of seeing and measuring the same sign multiple times while moving along the highway.

2.3.2 Real Time Measurements

The real time measurement capability has been described in section 1.4.3, and analysis results are shown in Appendix 5.

2.3.3 Multiple Measurements of the Same Signs

Because the same sign will appear in multiple frames as the vehicle moves toward and then past the sign, some mechanism is required to select one of the measurements. Empirical evidence shows that the sign's brightness is fairly constant from the time the sign is large enough to read, until it starts fading as the vehicle gets close and the entrance angle gets too large. Thus it was determined to record only the highest measured result. Figure 9 shows an example of this relationship, filmed at a rate of 10 frames per second.

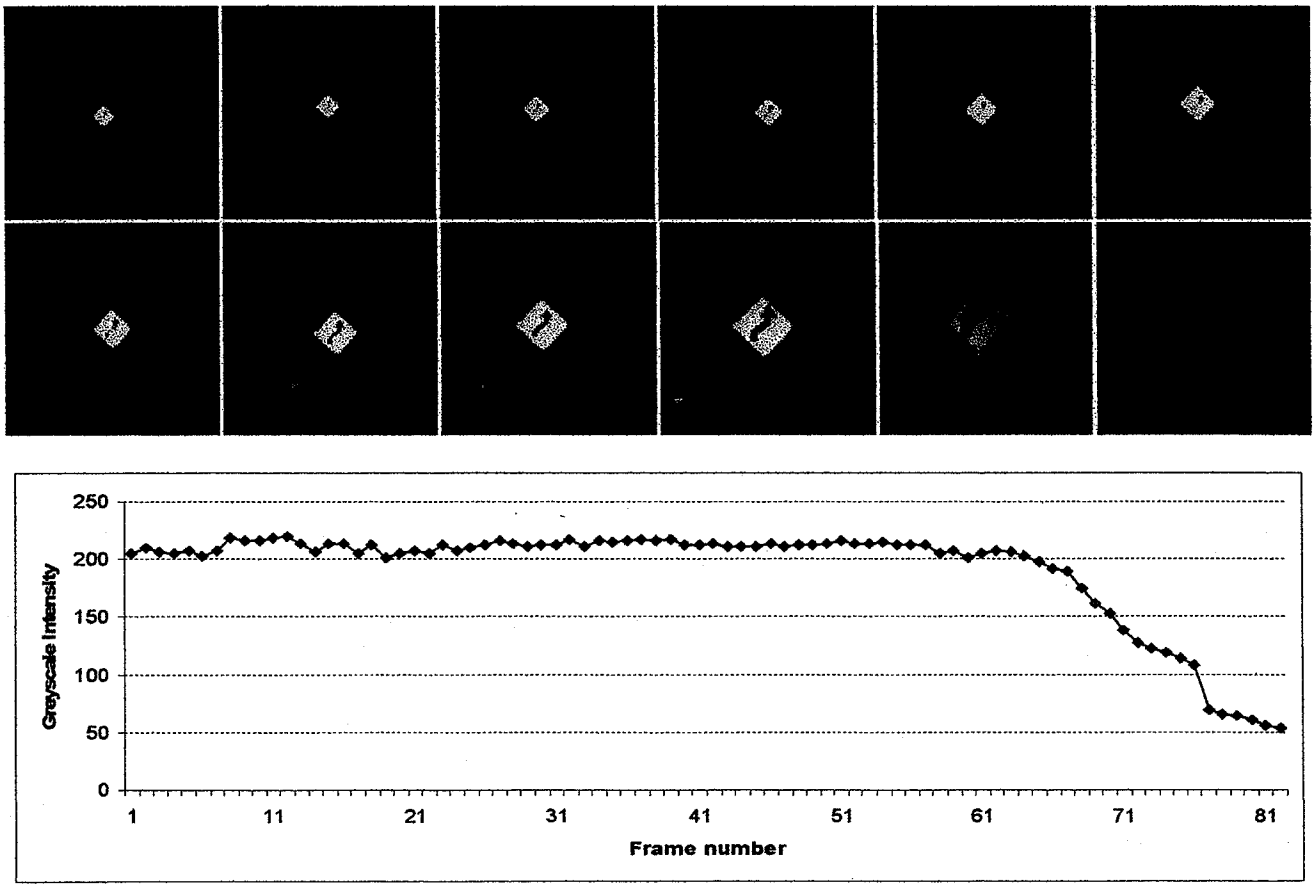


FIGURE 9. Top: Video sequence of a single yellow sign imaged along a highway (about every 8th frame is analyzed). Bottom: Brightness measurement of the yellow sign as a function of analyzed frame number (each frame showing a successively closer image of the sign).

2.4 Plans For implementation

The results of this investigation are published here and will be as well at the next Transportation Research Board Annual Meeting. Potential investors would be sought for the purpose of moving from a prototype to developing and marketing a final product. In the interim improvements will be made to measure in noisy highway scenes, including tracking multiple signs in the same sequence of images, identifying and rejecting light sources that are not signs, and separating signs that are touching or partially overlapped

3. CONCLUSIONS

Based on the results of this study the following conclusions can be made.

1. The concept of using a mobile vision based system to classify and to measure the visibility of roads signs is found to have merit, and promises to be a useful tool to ensure the safety of the motoring public at night.
2. This method will be the closest possible analog to what eyes see when looking at signs, incorporating the normal illumination provided by the headlights, and subject to the same geometric disadvantages with signs that are disadvantageously placed.
3. The measurement method is mobile, fast, and safe, and it is uses state of the art inexpensive technology.
4. The method must be used at night, and may possibly be limited to use with high beams, and is for the moment limited to signs that are relatively isolated, not overlapping or situated in a noisy background.

Further discoveries that have been made relate to the retroreflectivity of signs. The retroreflectivity and visibility of signs are often poorly correlated. In this study:

1. Retroreflectivity was found to be a poor predictor of the visibility of white, yellow and to a lesser extent orange signs. These signs tend to be fairly uniformly visible down to very low values of retroreflectivity.
2. Retroreflectivity is a relatively good predictor of the visibility of red, and to a lesser extent of green and blue signs. These signs tend to be of low retroreflectivity but high visibility.
3. Brown signs are of low retroreflectivity and low visibility.

4. REFERENCES

(1) FHWA. *Manual on Uniform Traffic Control Device (MUTCD) Millennium Edition*, 2001.

(2) Estevez, L, and Kehtarnavaz, N. *A Real-Time Histographic Approach to Road Sign Recognition.* Proceedings of the IEEE Southwest Symposium on Image Analysis and Interpretation, 1996, pp. 95-100.

(3) Miura, J., Kanda, T., and Shirai, Y. *An Active Vision System for Real-Time Traffic Sign Recognition.* 2000 IEEE Intelligent Transportation System Conference Proceedings, Dearborn (MI), USA, 2000, pp.52-57.

(4) Arens, J.B., Saremi, A.R., and Simmons. *Color Recognition of Retroreflective Traffic Signs Under Various Lighting Conditions.* C.J. Public Roads, 55, 1991, pp.1-7.

(5) Gavrila D. M., and Philomin. V. *Real-Time Object Detection For "Smart" Vehicles.* Proc. of IEEE International Conference on Computer Vision, Kerkyra, Greece, 1999, 7 pp.

(6) Gavrila D. M., and Philomin. *Real-Time Object Detection Using Distance Transforms.* Proc. of IEEE International Conference on Intelligent Vehicles, Stuttgart, Germany, 1999, 6 pp.

(7) Gavrila D. M. *Traffic Sign Recognition Revisited.* Proc. of DAGM Symposium für Mustererkennung, Bonn, Germany, 1999, 9 pp.

(8) Betke, M., and Makris, N. C. *Fast Object Recognition in Noisy Images Using Simulated Annealing*. Proceedings of the Fifth International Conference on Computer Vision, 1995, pp. 523-530.

(9) Lalonde, L. *Road Sign Recognition. - Survey of the State of the Art.* http://euler.fd.cvut.cz/research/rs2/other.html.

(10) Priese, L., Rehrmann, V., Schian, R., Lakmann, R. *Traffic Sign Recognition Based On Color Image Evaluation.* Intelligent Vehicles '93 Symposium, 1993, pp. 95-100.

(11) Kang, D. S., Griswold, N. C., and Kehtarnavaz, N. *An Invariant Traffic Sign Recognition System Based on Sequential Color Processing and Geometrical Transformation.* IEEE Southwest Symposium on Image Analysis and Interpretation, 1995, pp. 88-93.

(12) Zheng, Y, ritter, W., Janssen, R. *An Adaptive System for Traffic Sign Recognition.* Proceedings of Intelligent Vehicles '94, 1994, pp. 165-170.

(13) Liu, H. X., and Ram, B. *Vision-Based Stop Sign Detection and Recognition System for Intelligent Vehicle.* 2001 TRB Annual Meeting, 2001, 19 pp.

(14) Escalera, A., Moreno, L. E., Salichs, M. A., and Armingol, J. M. *Road Traffic sign Detection and Classification.* IEEE Transactions on Industrial Electronics, vol. 44, no. 6, 1997, pp. 848-858.

(15) Ritter, W. *Traffic Sign Recognition in Color Image Sequences.* Intelligent Vehicles Symposium, 1992, pp. 12-17.

(16) Ghica, D., Lu, S. W, and Yuan, X. *Recognition of Traffic Signs by Artificial Neural Network.* IEEE International Conf. on Neural Networks , Perth, Australia, 1995, pp. 1444-1449.

(17) Tong, W. B., Herve, J. Y., and Cohen, P. *Automated Traffic Sign Recognition.* 32 ISAT: Advance in Automotive and Transportation Technology and Practice for the 21st Century, 1999, pp. 497-503.

(18) Kehtarnavaz, N., Griswold, N. C., and Kang, D. S. Stop-sign Recognition Bases on Color/shape Processing. Machine Vison and Applications, vol. 6, 1993, pp. 206-208.

(19) Black, K. L., McGee, H. W., and Hussain, S. F. *Implementation Strategies for Sign Retroreflectivity Standards.* National Cooperative Highway Research Program Report 346, Transportation Research Board, 1992, 18 pp.
(20) Simmons, C. J., and Paniati, J. F. *Developing Minimum Retro reflectance Values for In-Service Traffic Signs.* 1995 Compendium of Technical Papers, Institute for Transportation Engineers Proceedings of The 65th Annual Meeting of the Institute for Transportation Engineers, 1995, pp 597-600.

(21) Paniati, J.R. and Mace, D. J. *Minimum Retroreflectivity Requirements for Traffic Signs.* FHWA-RD-93-077 (FHWA-RD-93-152), Federal Highway Administration, Washington DC, 1993.

(22) Mace, D. J., Hostetter, R. S., and Pollack, L. E. *Minimum Luminance Requirements for Official Highway Signs.* FHWA-RD-86-151, Federal Highway Administration, Washington DC, 1986.

(23) Hawkins, H. G., and Carlson., P. J. *Results of Visual Evaluations of Sign Retroreflectivity Compared to Minimum Retroreflectivity Recommendations.* Paper 01-2464, 80th Annual Meeting of the Transportation Research Board, Washington D.C., Jan 2001, 22 pp.

(24) Bhise, V. D., Farber, E. I., and McMahan., P. B. *Predicting Target-Detection Distance with Headlights.* Transportation Research Board, 1976. Transportation Research Record, vol. 611, 1976, pp. 1-16.

(25) Farber, E. *Revising the DETECT Seeing Distance Model. Eugene Farber.* Society of Automotive Engineers publication 880716, 1988, 15 pp.

(26) Simmins, C. J., and Paniati, J. F. *Developing Minimum Retroreflectance Values for In-Service Traffic Signs.* Institute of Transportation Engineers 65th Annual Meeting, 1995, pp. 597-599.

(27) Lumia, J.J. *Mobile System for Measuring the Retroreflectance of Traffic Signs.* Transportation Research Record 1247, 1989, pp. 69-78.

(28) Hatzi. P., Sign Retroreflectometers: *How Do They Work?* FHWA, http://www.fhwa.dot.gov/safety/fourthlevel/pdf /signs.pdf

(29) Hatzi, P., Retroreflectivity: Raising *the Nighttime Brightness of Traffic Signs and Marking.* FHWA/Safety HAS-1, http://www.fhwa.dot.gov/safety/fourthlevel/pdf/overview.pdf.

(30) FHWA. *Draft Retroreflectivity Sign Van Operators Manual,* 1999, 10 pp. http://www.fhwa.dot.gov/safety/fourthlevel/pdf/RetroManual.pdf

(31) Maerz, N. H., and Swindall, B., and Davies, C. *Automated real time pavement marking retroreflectivity measurements.* Transportation Research Board, 78th Annual Meeting, Jan 10-14, 1999, 14 pp.

(32) Maerz, N. H., and McKenna, S. *Mobile highway inventory and measurement system.* Transportation Research Record No. 1690, 1999, pp. 135-142.

(33) U. S. Department of Transportation. *Manual on Uniform Traffic Control Devices, Millennium Edition.* U.S. Government Printing Offices, Washington, D.C., 2000.

Microsoft Foundation Classes®, Microsoft Windows®, DirectShow®, COM®, Microsoft Visual C++®, DirectX®, Microsoft Windows Driver Model®, and Internet Explorer® are registered trademarks of Microsoft Corporation.

APPENDIX 1: RETROREFLECTIVITY* MEASUREMENTS

SIGN**	Bright Color***	Specific Color****
Yellow (curve)	238 86 16 5	-
White (speed limit)	299 104 77 53 24 3	-
Red (stop)	295 77 261 38	31 23 48 10
Yield	286 71 43 37	33 20 9 4
Blue (service)	305 64 102	21 8 4
Brown (public use)	293 90 62 55	17 6 4 3
Green (town)	300 84 52 75	51 12 3 11
Orange (construction)	104 35 32	-

*Coefficient of reflected luminance (R' in cd/m2.lux)

**4 versions for each sign: 1) New high grade sheeting; 2) New Engineer grade sheeting; 3) Used, taken out of service for this project; 4) Used, had previously been taken out of service because of loss of performance. For blues and orange it was not possible to get all versions. For white two extra poor quality signs were added to get a complete range of retroreflectivities. For orange, only three signs were made available.

***Bright color is white background on speed sign, yellow on curve sign, orange on construction sign, or white lettering on other signs.

****Dull color is the background on the other signs (red, green, blue, brown). Black is not considered as it has 0 retroreflectivity.

APPENDIX 2: STATIC BRIGHTNESS* MEASUREMENTS

SIGN**	Bright Color***							Specific Color****						
	Aug 22	Aug 25	Sep 26	Nov 9	Nov 11	Nov 11[x]		Aug 22	Aug 25	Sep 26	Nov 9	Nov 11	Nov 11[x]	
Yellow (curve)	204 172 135 94	198 163 124 68	219 209 124 68	214 201 149 76	226 214 190 101	185 181 159 98		-	-	-	-	-	-	
White (speed limit)	204 187 198 173	197 179 191 165	207 209 205 190	185 189 182 147 115 31	213 213 212 192 195 104	204 205 207 190 156 145		-	-	-	-	-		
Red (stop)	188 162 181 148	177 146 167 127	189 172 172 162	185 176 167 155	178 169 174 172	173 176 180 152		208 187 219 113	185 185 205 108	230 232 231 149	224 218 224 146	215 226 191 185	142 128 152 112	
Yield	213 190 183 151	203 176 170 132	202 186 175 147	188 176 183 167	185 172 188 165	181 162 149 126		221 203 125 71	223 217 135 71	224 226 144 77	218 215 170 100	209 216 189 102	111 124 90 59	
Blue (service)	195 201 194	183 185 184	191 198 196	191 198 197	194 198 195	184 191 184		240 241 206	236 234 200	233 221 212	233 225 212	230 228 216	178 176 170	
Brown (public use)	165 137 133 114	149 115 121 92	153 126 150 108	163 134 142 110	169 139 154 119	124 100 93 85		56 46 45 42	37 30 38 37	39 33 42 39	45 36 40 39	49 39 38 39	38 32 32 35	
Green (town)	199 169 156 180	188 156 140 140	199 184 165 174	195 186 163 174	200 189 170 182	183 155 144 149		169 113 72 109	166 109 69 106	203 149 88 145	208 150 83 143	214 162 90 163	131 106 74 110	
Orange (construc -tion)				179 153 152	205 185 185	183 115 115		-	-	-	-	-	-	

*in greyscale units, 0-255, red buffer-red sign, green buffer-green sign, blue buffer-blue sign, average of red, green, blue buffer, white sign and brown sign, average of red and green buffer, yellow sign and orange sign.

**4 versions for each sign: 1) New high grade sheeting; 2) New Engineer grade sheeting; 3) Used, taken out of service for this project; 4) Used, had previously been taken out of service because of loss of performance.

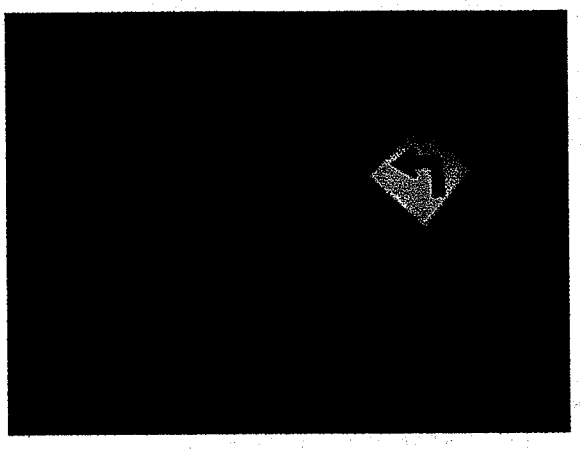
***Bright color is white background on speed sign, yellow on curve sign, orange on construction sign, or white lettering on other signs.

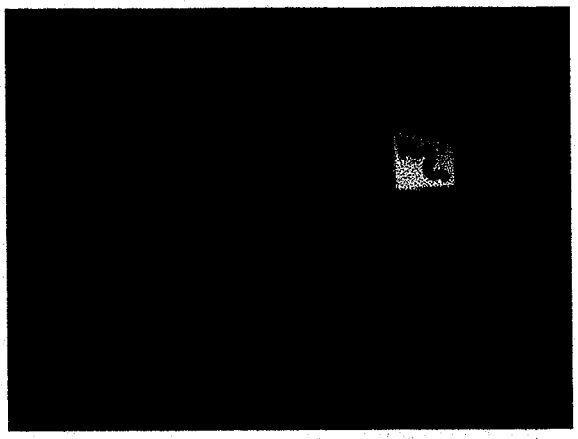
****Specific color is the background on the other signs, red, green, blue, brown. Black is not considered as it has 0 retroreflectivity.

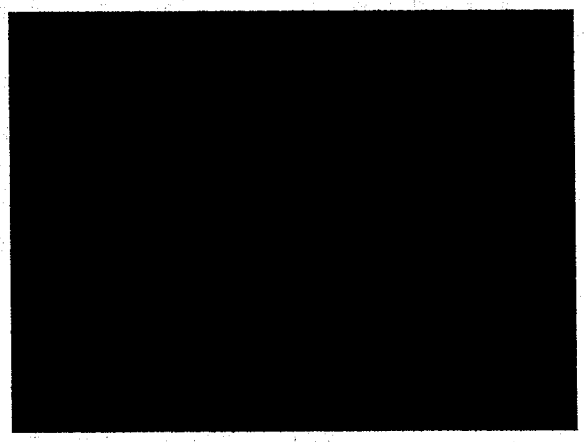
[d]enotes analysis done with low beam lights, with larger camera aperture and amplifier settings.

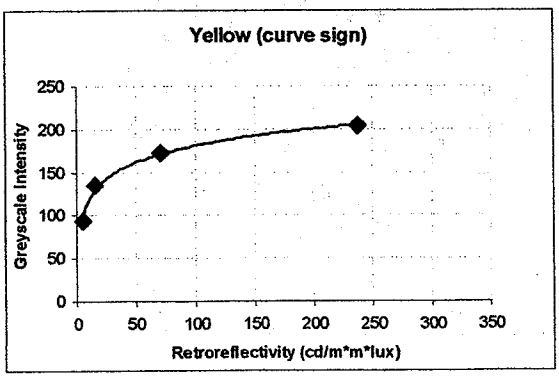
APPENDIX 3: TEST SIGN IMAGES AND CORRELATION BETWEEN RETROREFLECTIVITY AND BRIGHTNESS

YELLOW (YIELD) SIGNS

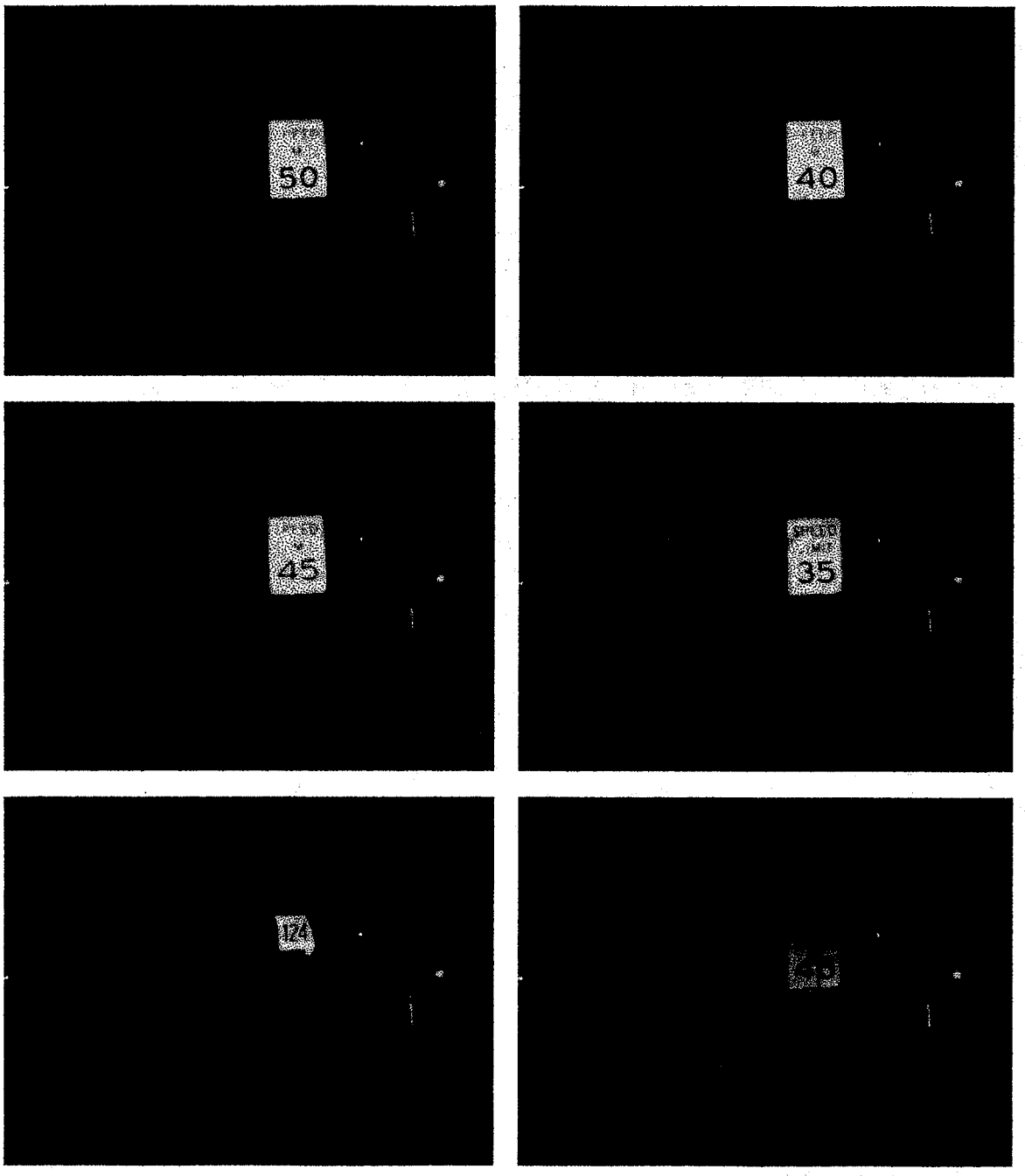


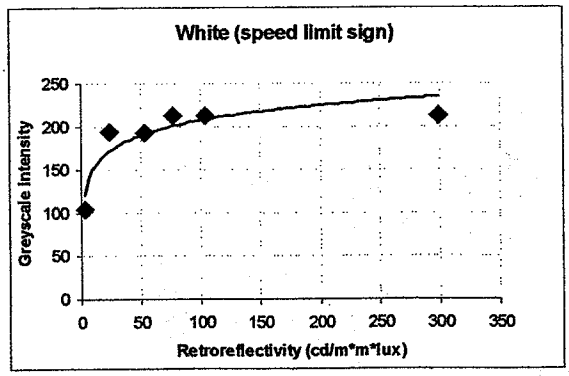




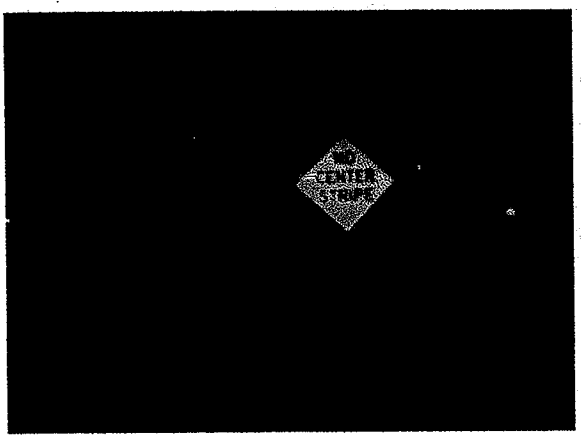


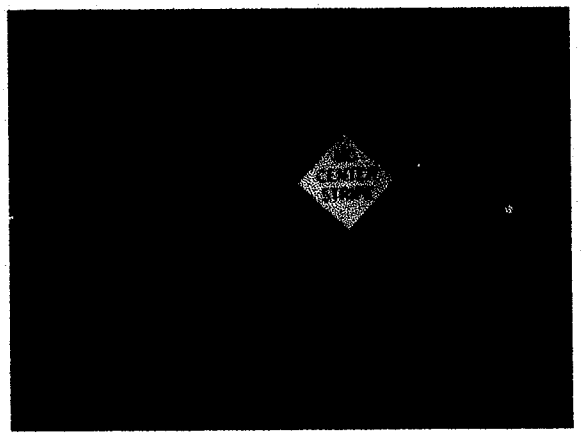
WHITE (SPEED) SIGNS

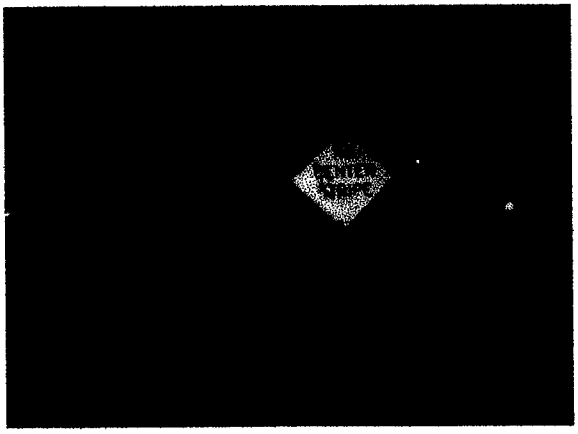


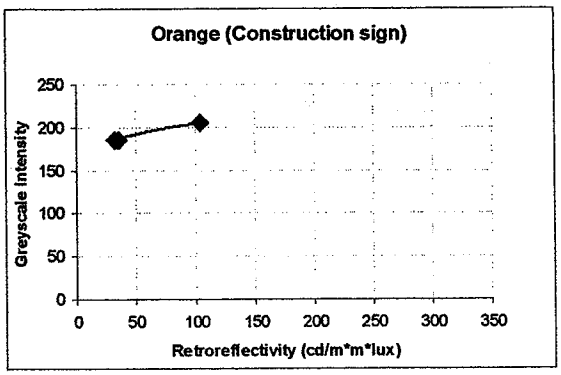


ORANGE (CONSTRUCTION SIGNS)

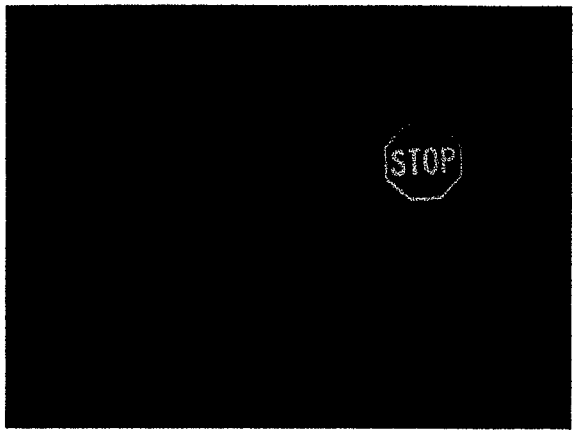


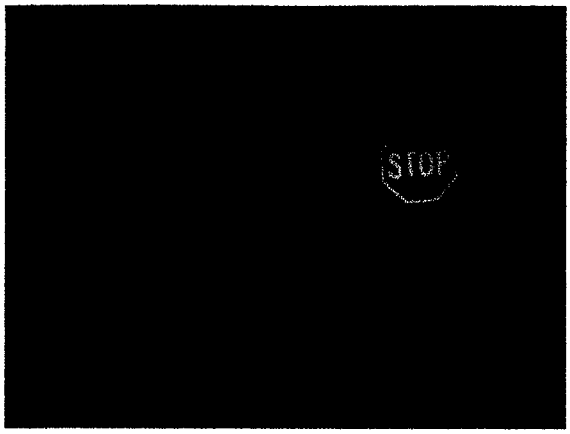


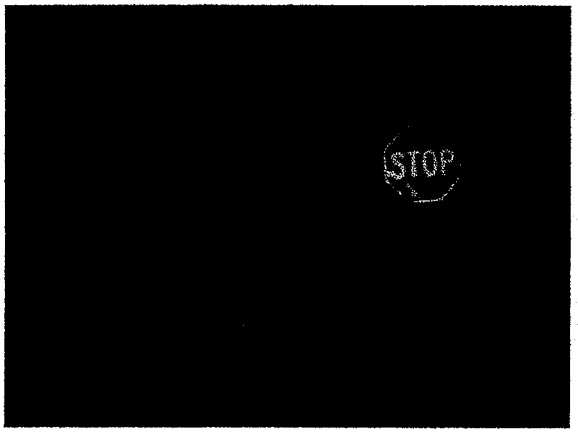


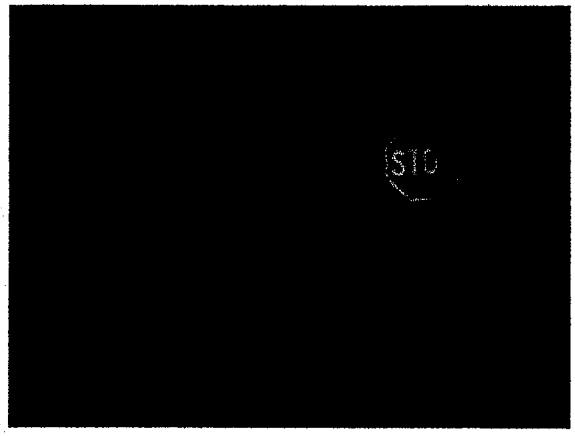


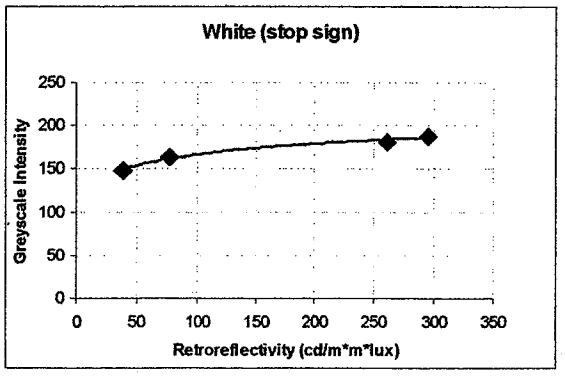
RED (STOP) SIGNS

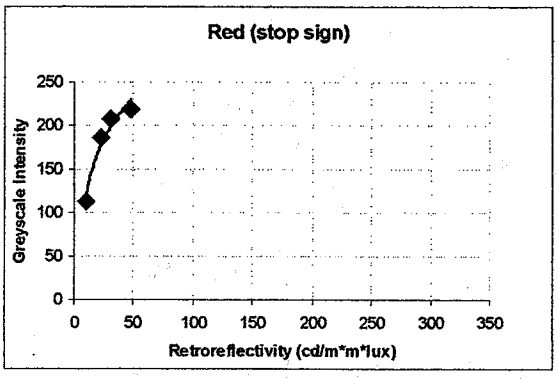




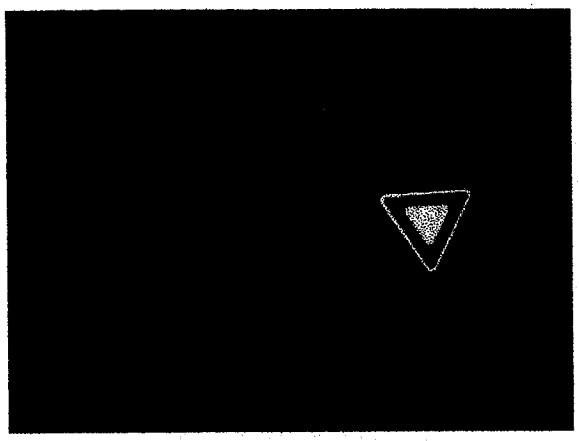


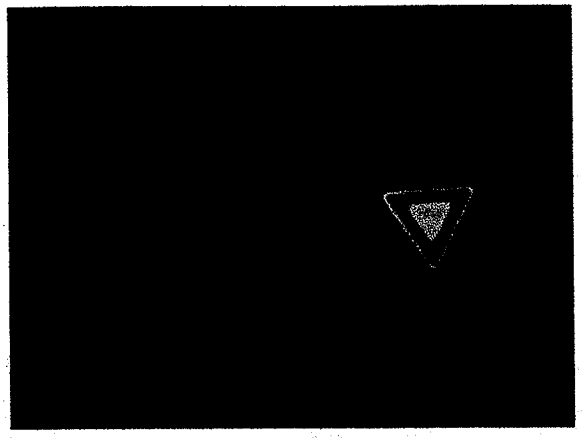


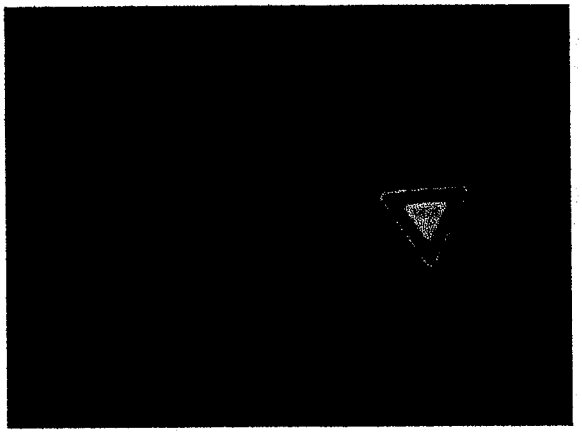


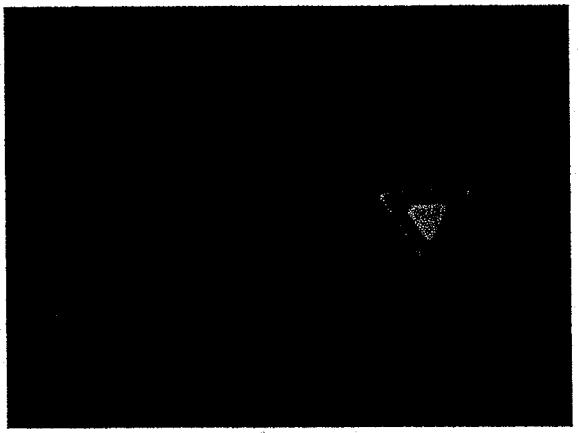


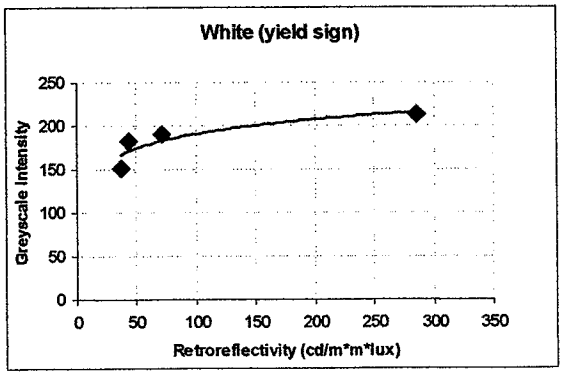
YIELD SIGNS

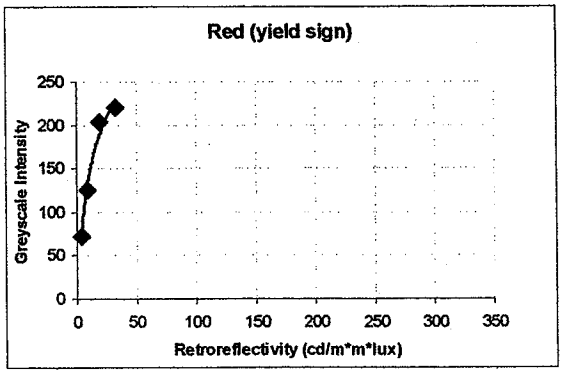




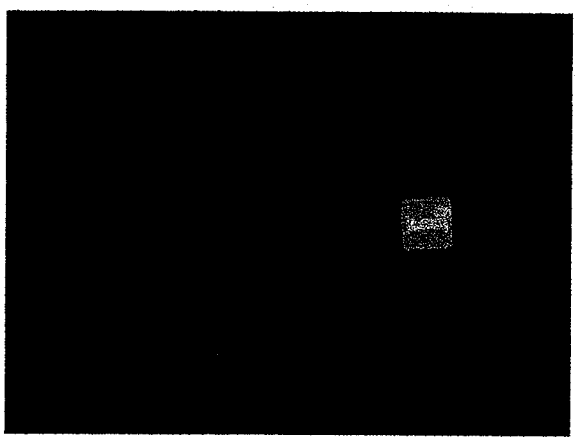


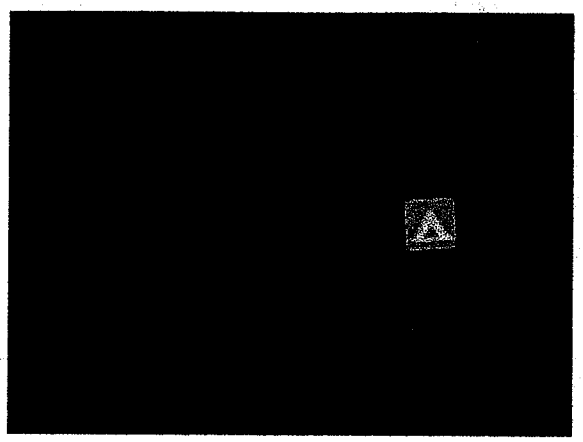


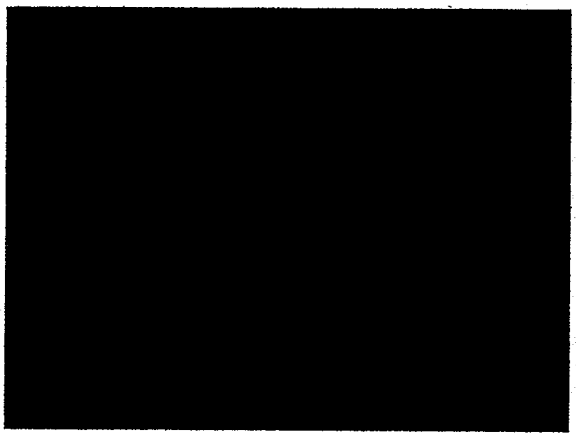

White (yield sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
350
Retroreflectivity (cd/m*m*lux)

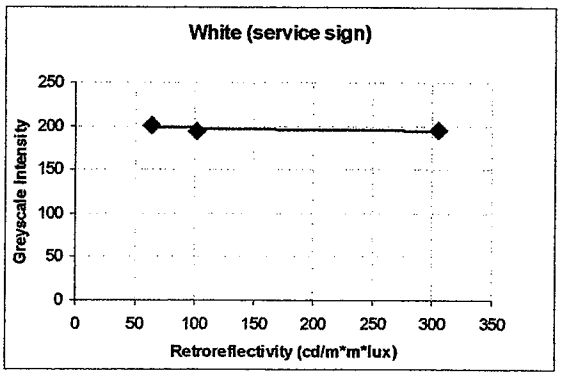

Red (yield sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
350
Retroreflectivity (cd/m*m*lux)

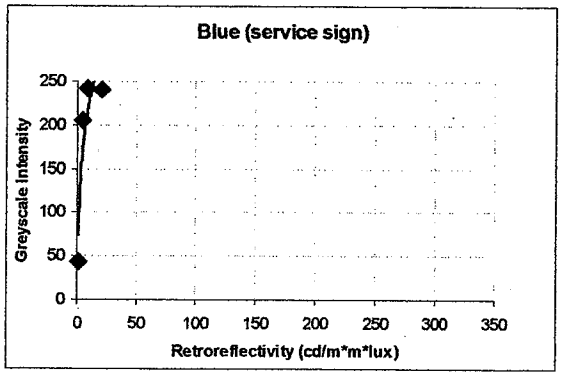
BLUE (SERVICE) SIGNS



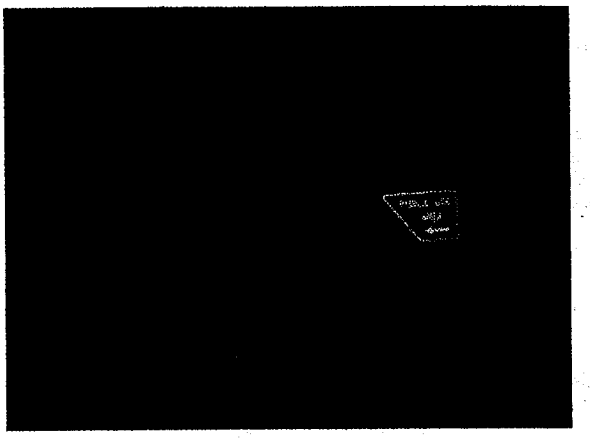


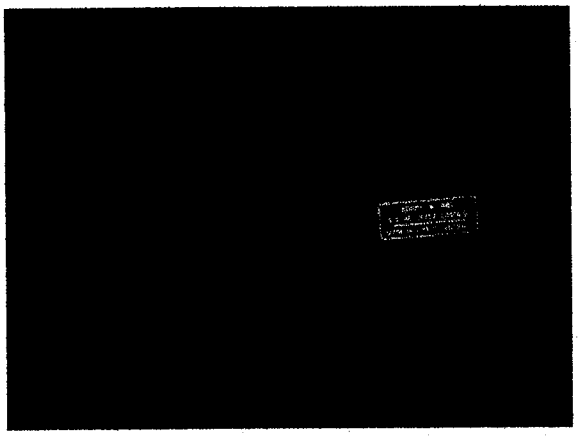


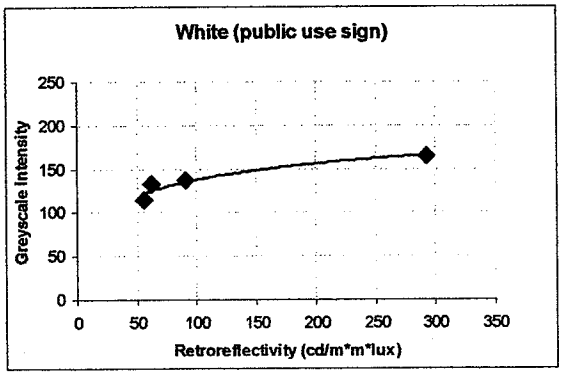


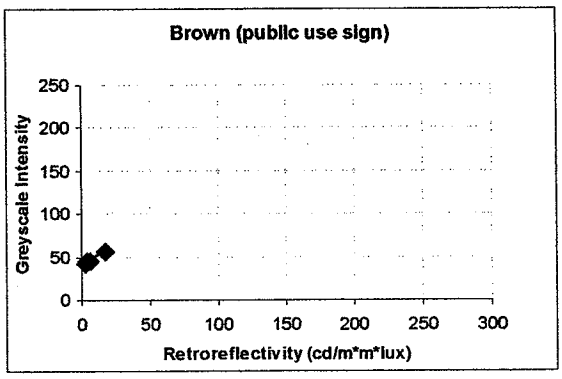


BROWN (PUBLIC USE) SIGNS

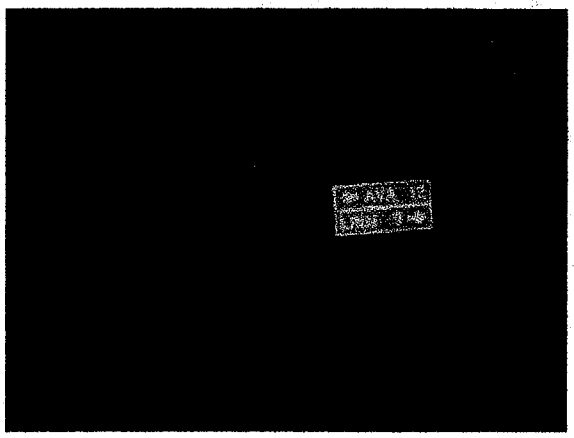


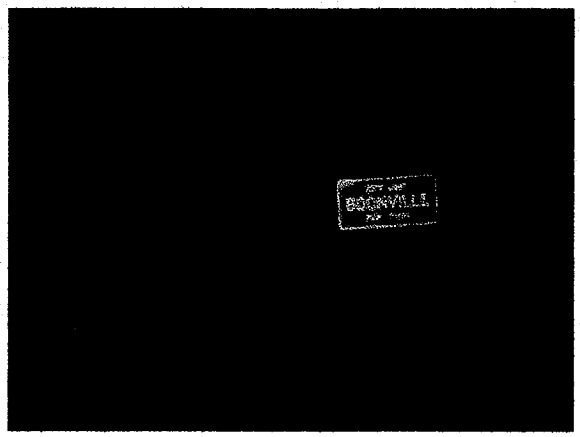


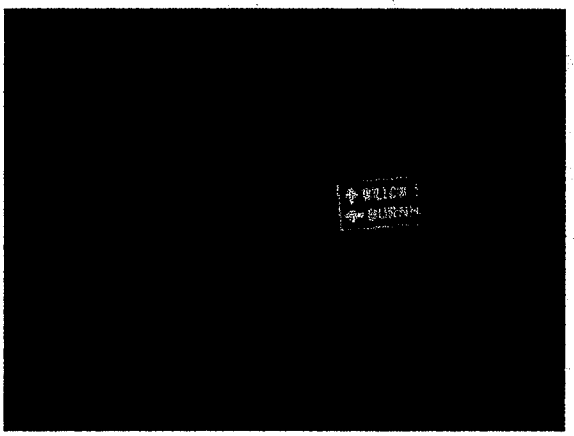


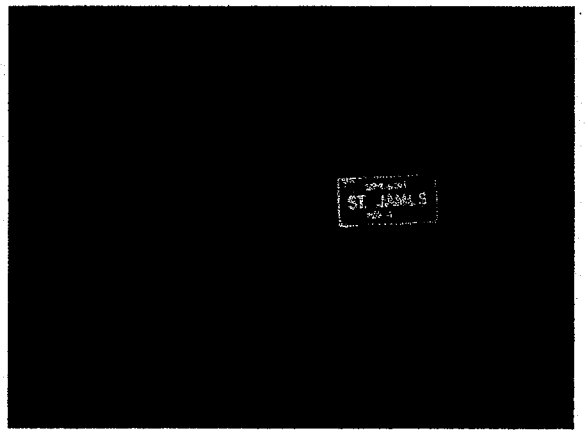


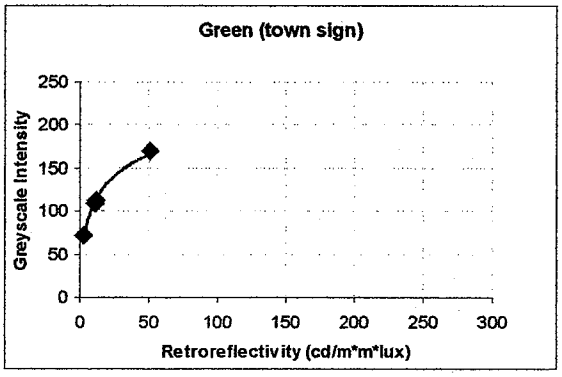
GREEN (CITY) SIGNS





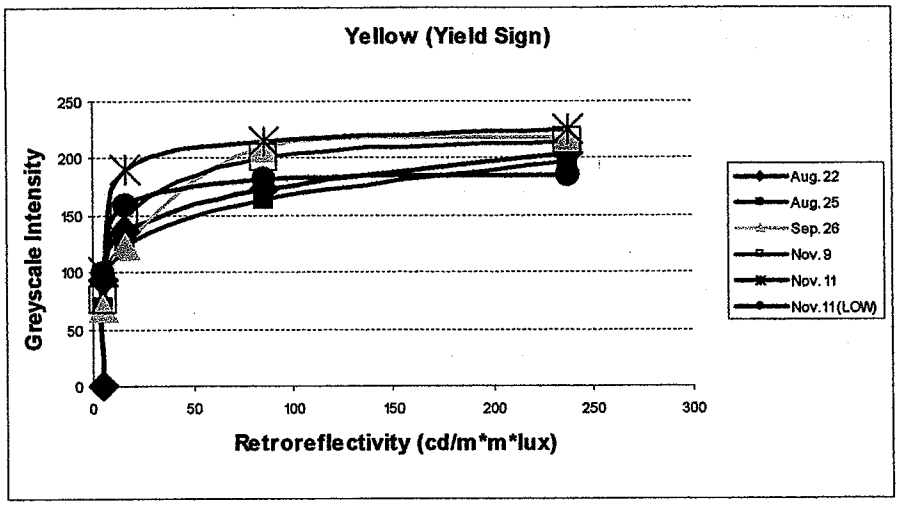


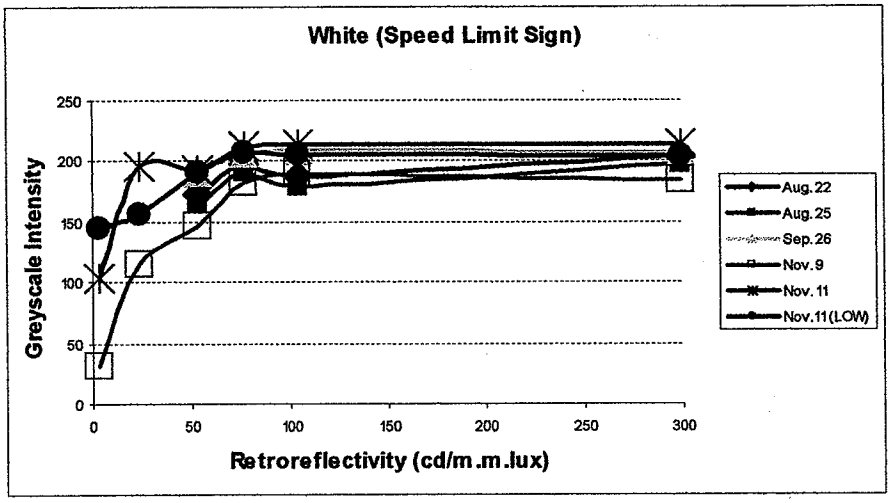


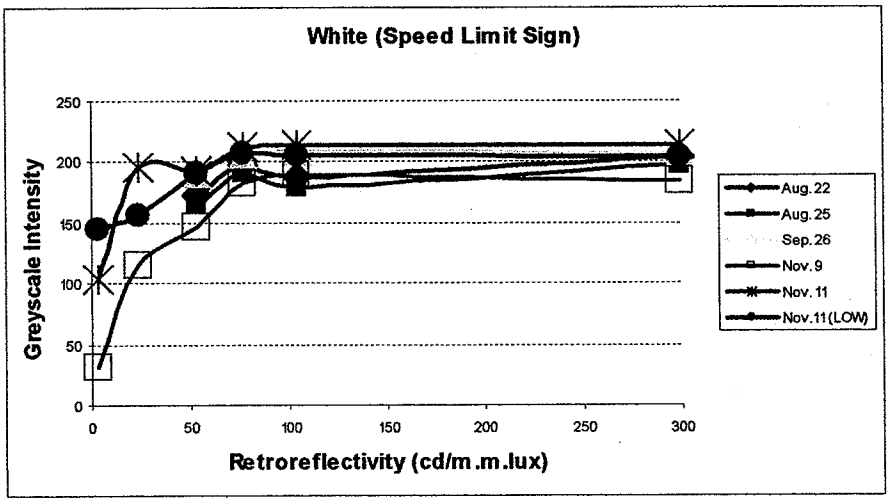


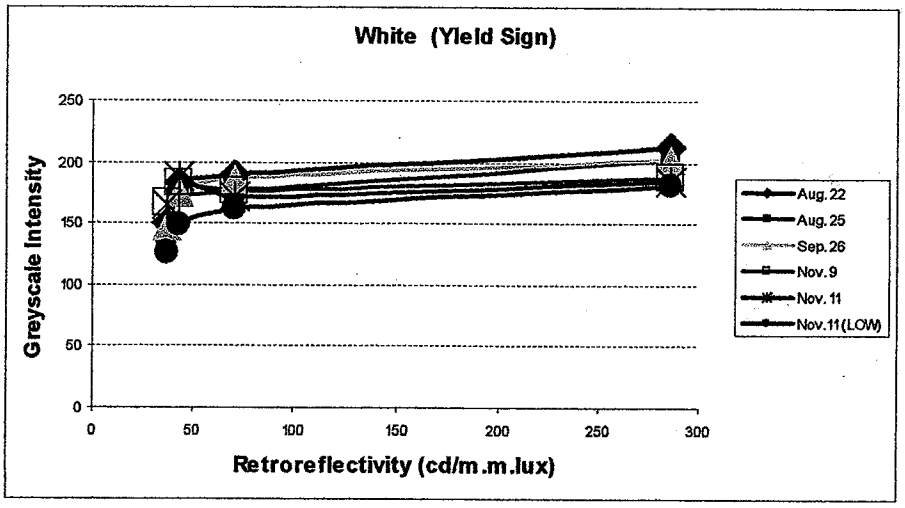
APPENDIX 4: REPRODUCIBILITY STUDIES

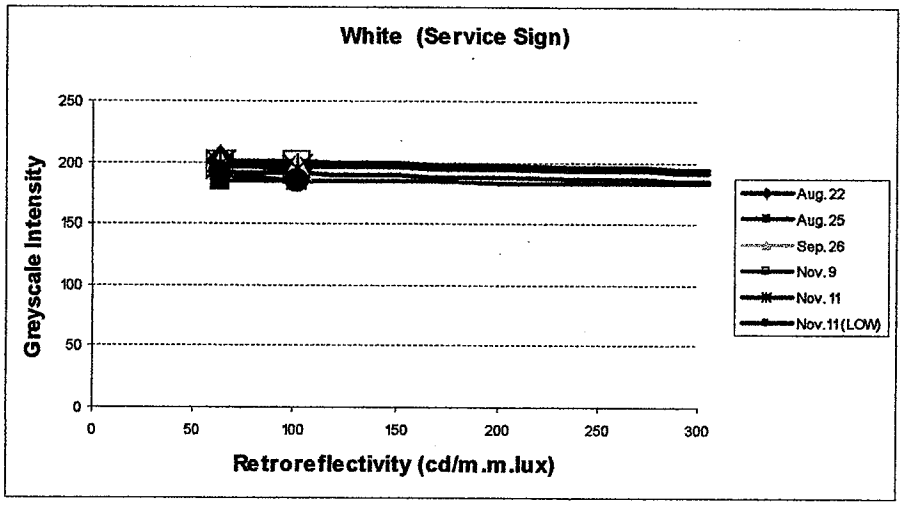
BRIGHT COLORS

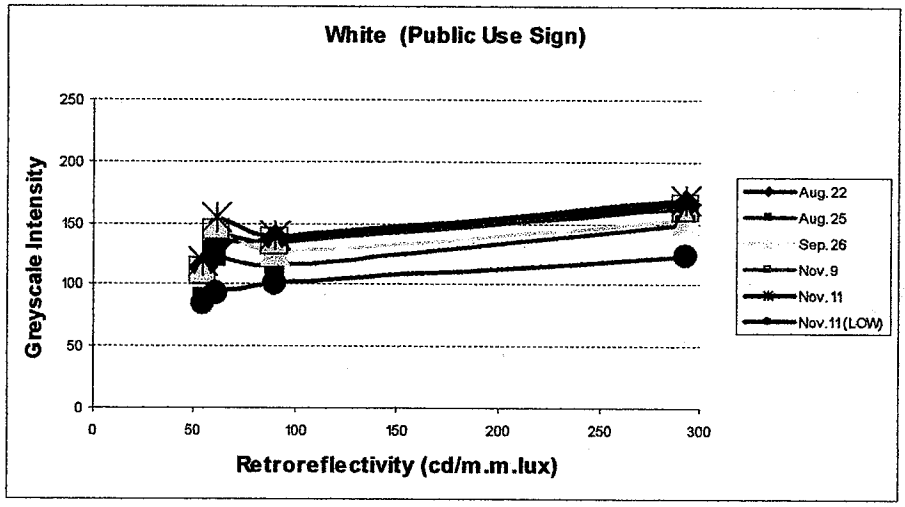


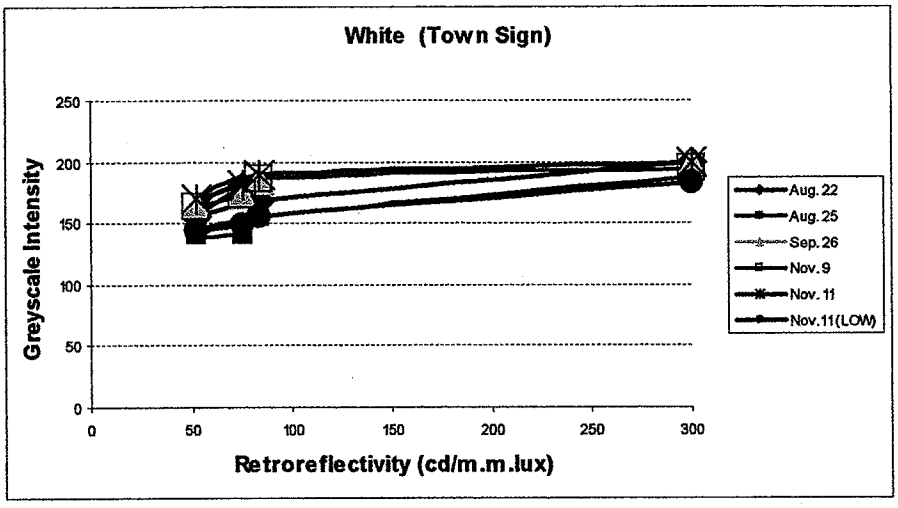


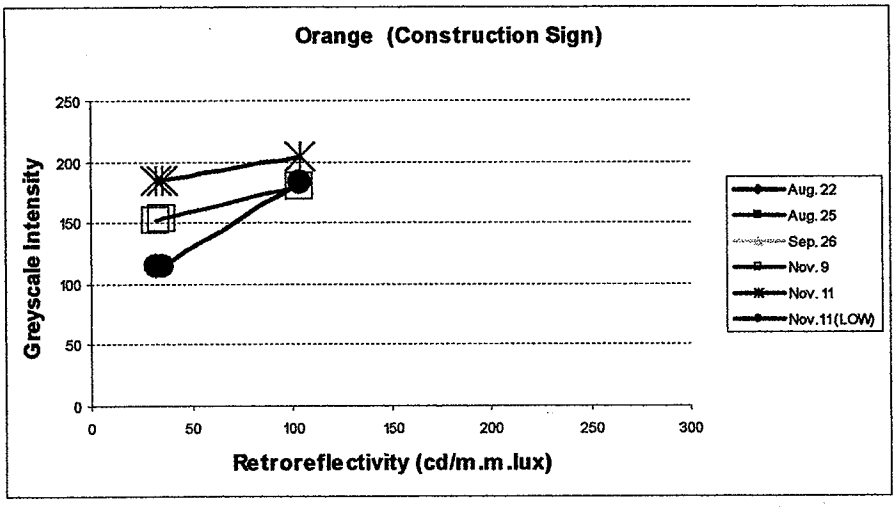



White (Yield Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov.11(LOW)

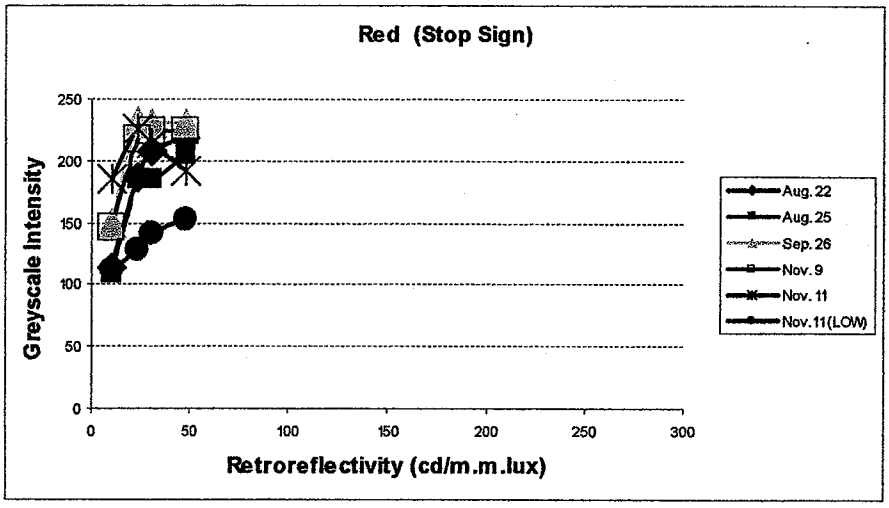

White (Service Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov.11(LOW)

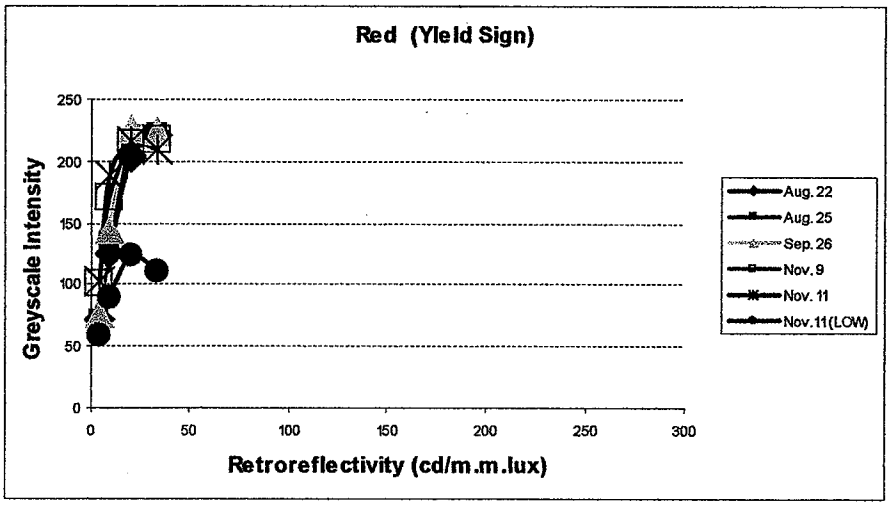

White (Public Use Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov.11(LOW)

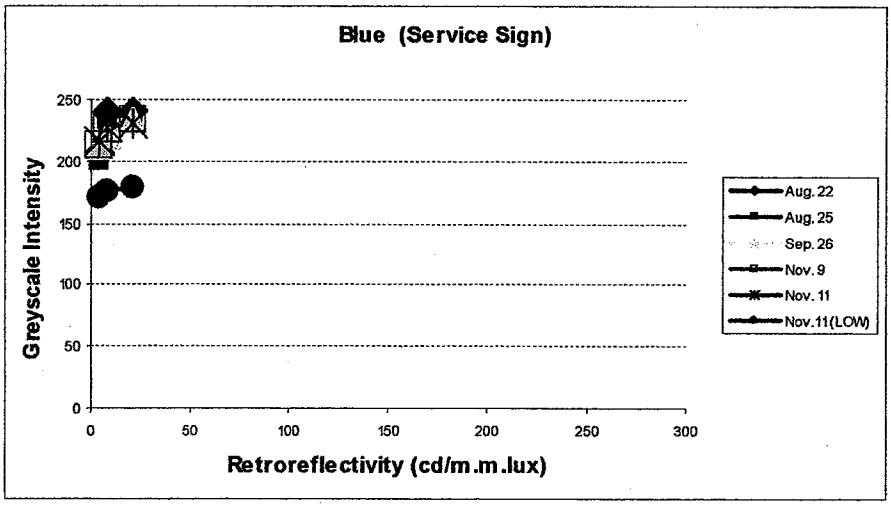

White (Town Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov.11(LOW)

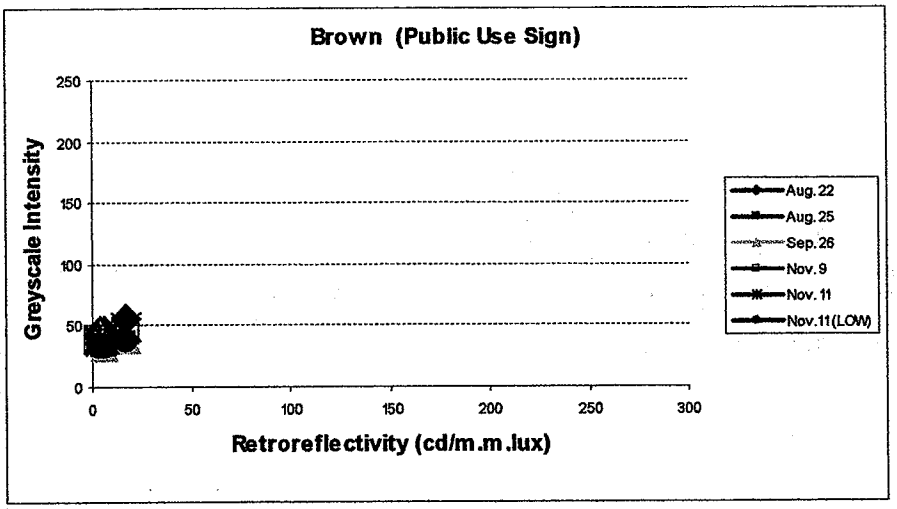

Orange (Construction Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov.11(LOW)

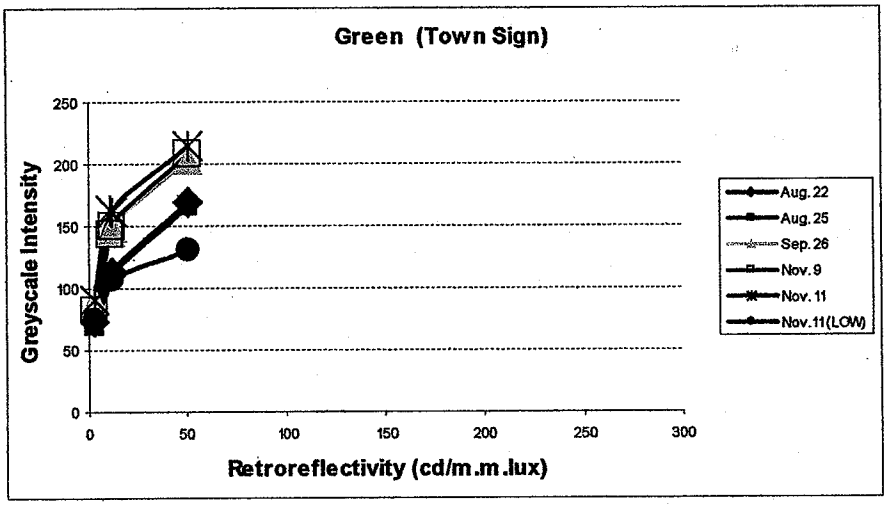
SPECIFIC COLORS



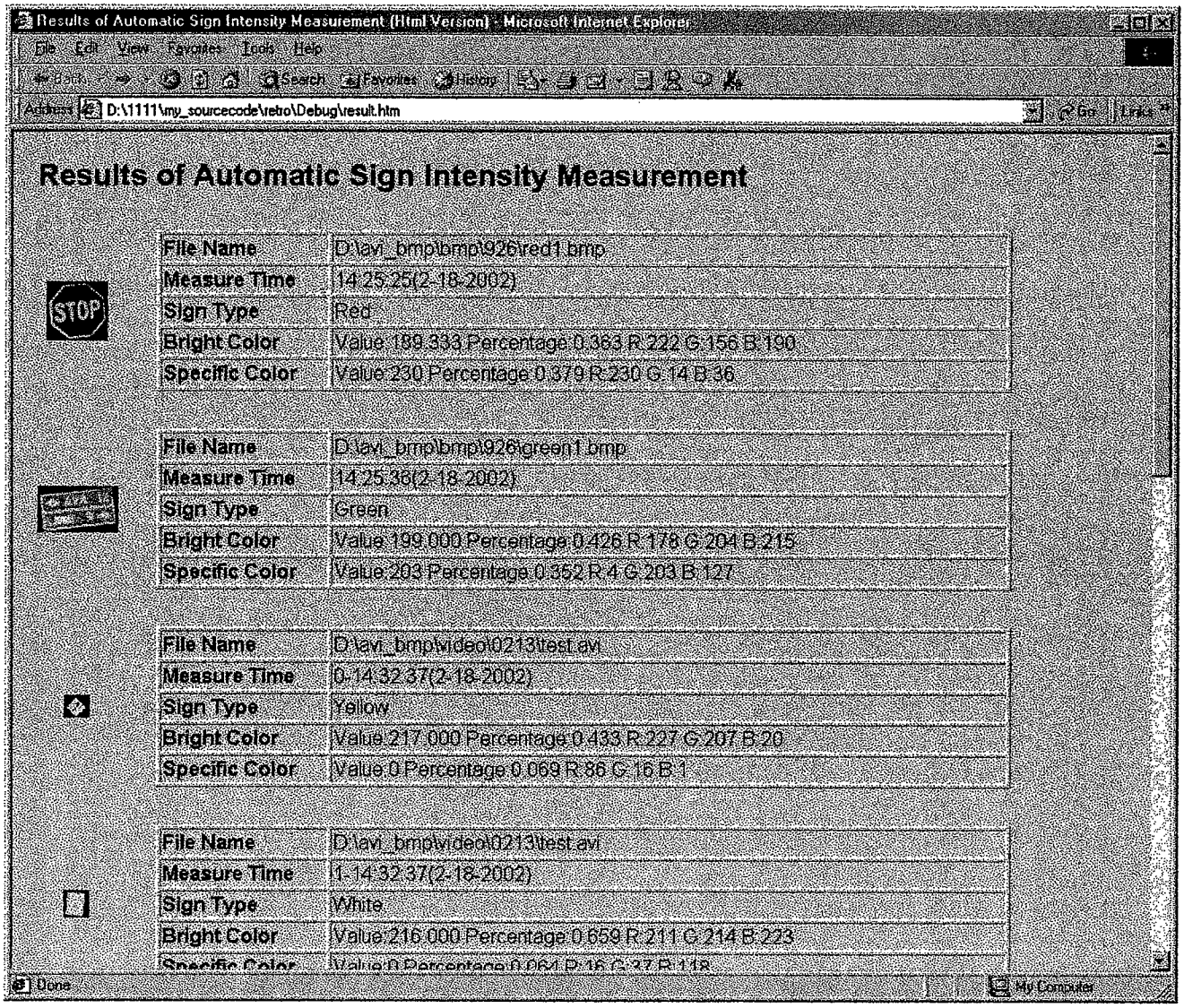





Brown (Public Use Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov. 11(LOW)


Green (Town Sign)
Greyscale Intensity
250
200
150
100
50
0
0
50
100
150
200
250
300
Retroreflectivity (cd/m.m.lux)
Aug. 22
Aug. 25
Sep. 26
Nov. 9
Nov. 11
Nov. 11(LOW)

APPENDIX 5: TYPICAL HTML DATA OUTPUT FILE



Typical data in html output format, displayed in Internet Explorer®, showing a thumbnail image, time of measurement, sign type, sign measurement of both the "bright" and "specific" colors.