

## **Automated Mobile Highway Sign Visibility Measurement System**

**Norbert H. Maerz**, University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660, Tel: (573) 341-6714, Fax: 573 341-4368, Email: [norbert@umr.edu](mailto:norbert@umr.edu)

**Qiang Niu**, University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660, Tel: (573) 341-6714, Fax: 573 341-4368, Email: [qniu@umr.edu](mailto:qniu@umr.edu)

**This paper describes a prototype of a digital video image analysis system that measures the relative luminance 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 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.**

**This is an improvement over current practice for ensuring that the signs are performing at night as required. Current methods consist 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.**

**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.**

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## **INTRODUCTION**

### **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 (Figure 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 regulatory, warning and guide signs must be made retroreflective, but does not yet specify minimum retroreflectivity standards. In response to a 1993 US congressional directive 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.

### **The Objectives of the Research**

The objective of this research was 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 would be 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 the physical extent of a sign.

### **Previous Research**

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 includes laser-based pavement stripe retroreflectivity (31) and mobile imaging of highway features for inventorying (32).

## **DESCRIPTION OF THE MEASUREMENT SYSTEM**

### **Introduction**

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 relative luminance of the images in real time, and reports results to a data file.

### **Hardware Requirements**

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 (Figure 1).

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 with a 25mm f/1.4 lens.

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.

### **Software Components**

#### *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.

#### *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 (actually shutter speed) can be set, and most importantly, any automatic settings can be disabled (Figure 2). This is critical to producing reproducible measurements, and eliminates the need for continual calibration.

### *Purpose Designed Image Analysis*

In order to measure the signs, the individual signs must be isolated within the image, classified, and measured, and the data must be stored in a meaningful way. The software interface is shown in figure 3.

#### **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) (1), 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 values in the red, green, and blue (R,G,B) buffers, 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 G B and the specific color's R G B, then it is white sign;  
Else if the bright color's  $R \gg B$  ( $R/B > 3$ ), it is a yellow sign;  
Else it is orange sign;

Else

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

#### **Sign Luminance Measurement**

The relative luminance (brightness) is defined simply the measure of the value of one or average value more of the R,G,B buffers on a scale of 0 to 255:

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 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 (Figure 4).

### **Software User Interface**

In this application, there are three analysis modes, allowing analysis from live streaming video, recorded video (AVI files) and static images (BMP files).

### **System Capabilities and Limitations**

This methodology is capable of measuring the relative luminance 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.

Limitations of the method include the necessity of making measurements at nighttime, and the fact that measurements are more efficient using high-beam illumination, which is more disruptive to oncoming 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.

### **Potential Impact of the Measurement System**

The potential impact of this technology is tremendous. It will provide the tool to effectively measure the performance 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.

## **SIGN MEASUREMENT INVESTIGATIONS**

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.

### **Static Studies**

#### *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 (guide), 4 signs,
8. Orange (construction) 3 signs.

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

1. New sign with high intensity 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. No blue sign or orange sign of appropriate retroreflectivity values could be found (to be taken out of service), and. For the white signs, two additional signs were added, to cover the range of low retroreflectivity.

### *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 1), 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.

### *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 driving 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 vehicle was 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.

### *Static Testing Results*

#### **Relationship Between Measured Brightness and Retroreflectivity**

The relationship between the measured relative luminance of the signs and the retroreflectivity was determined by tests on the static range. An example analysis is given in Figure 5. The retroreflectivity and relative luminance 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 luminance, 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 luminance, i.e. visibility is very sensitive to retroreflectivity. This is true not only for the red and white yield signs, but for all the signs tested.

#### **Reproducibility Studies**

Figure 6 shows examples of imaging and measuring 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.

#### **High Beam vs. Low Beam Analysis**

To make measurements using low beams requires modifications to the camera setup. To accommodate this, the lens aperture was increased, 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 7).

### *Dynamic Testing Results*

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.

#### **Real Time Measurements**

The real time measurement capability has been demonstrated using the new software.

#### **Multiple Measurements of the Same Image**

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 luminance 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 8 shows an example of this relationship, filmed at a rate of 10 frames per second.

### **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 road 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 may 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 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 luminance 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 luminance of red, and to a lesser extent of green and blue signs. These signs tend to be of low retroreflectivity but high visibility.

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FIGURE 4 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.

FIGURE 5 Typical analysis, 4 generations of yield sign, showing the correlation between measured intensity and retroreflectivity. The visibility of the “white” part of the sign is not very sensitive to the measured retroreflectivity, while the visibility of the “red” part of the sign is very sensitive to the measured retroreflectivity.

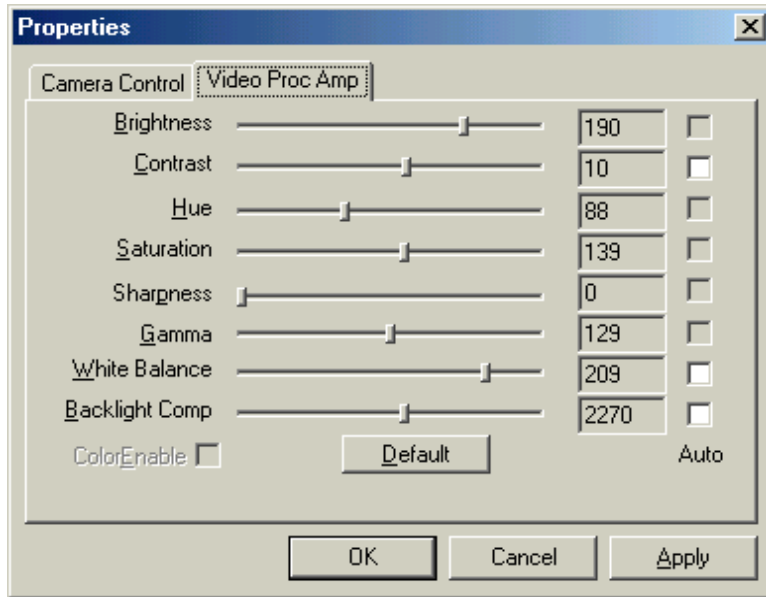
FIGURE 6 Typical repeat analysis results. In each case the vehicle position was changed randomly to simulate that fact that under normal driving conditions vehicle wander would result in a slightly different observation angle. The brown (circular symbol) line shows the result of using low beams for illumination.

FIGURE 7 Top left: High beam image. Top right: Low beam image. Note increase of background noise. Bottom left: High beam image. Bottom right: Low beam image. Note that the green sign in the left image almost completely disappears in the cluttered background of “lit” signs

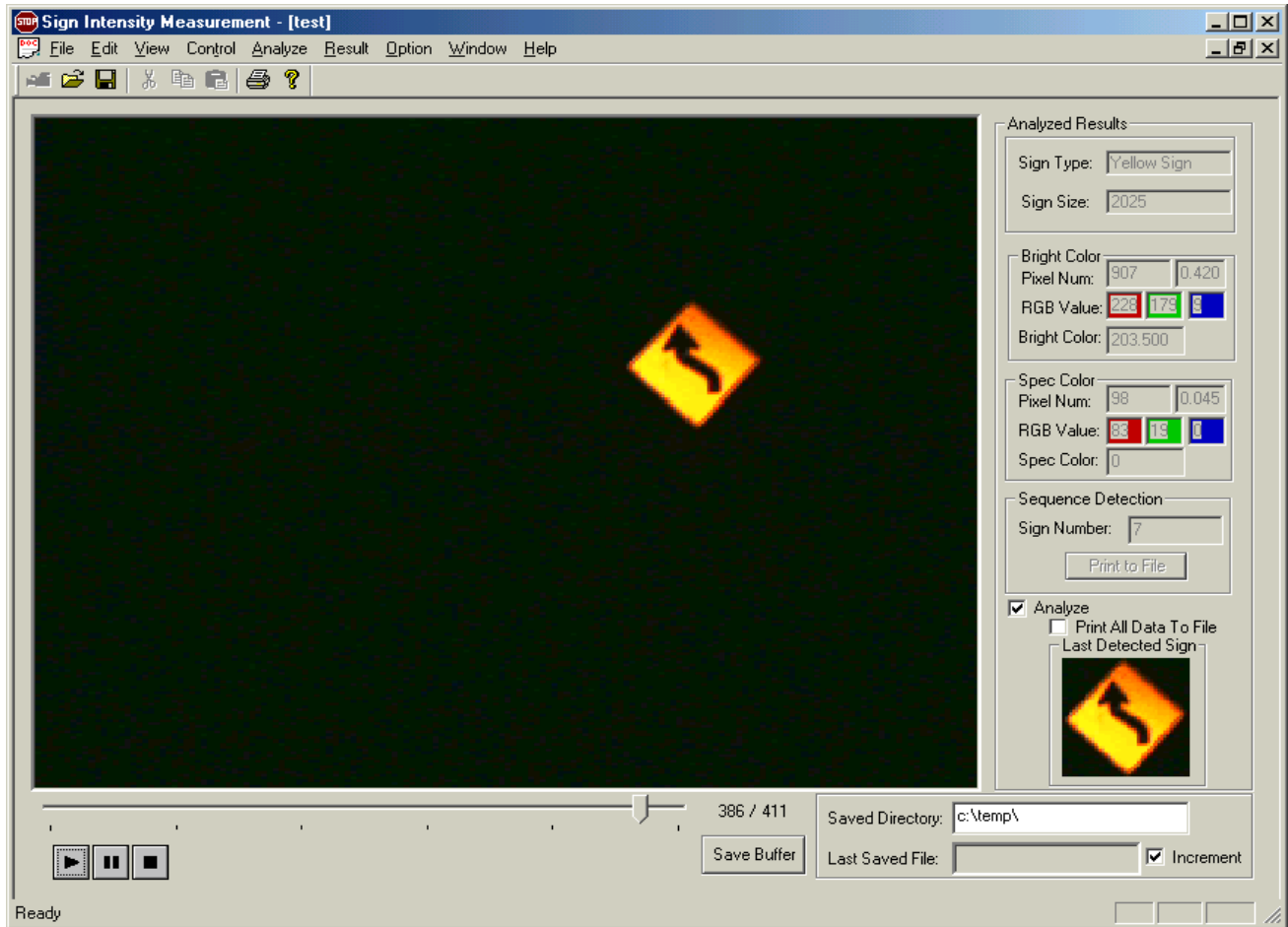
FIGURE 8 Top: Video sequence of a single yellow sign imaged along a highway (about every 8<sup>th</sup> frame is displayed). Bottom: Brightness measurement of the yellow sign as a function of analyzed frame number (each frame showing a successively closer image of the sign).



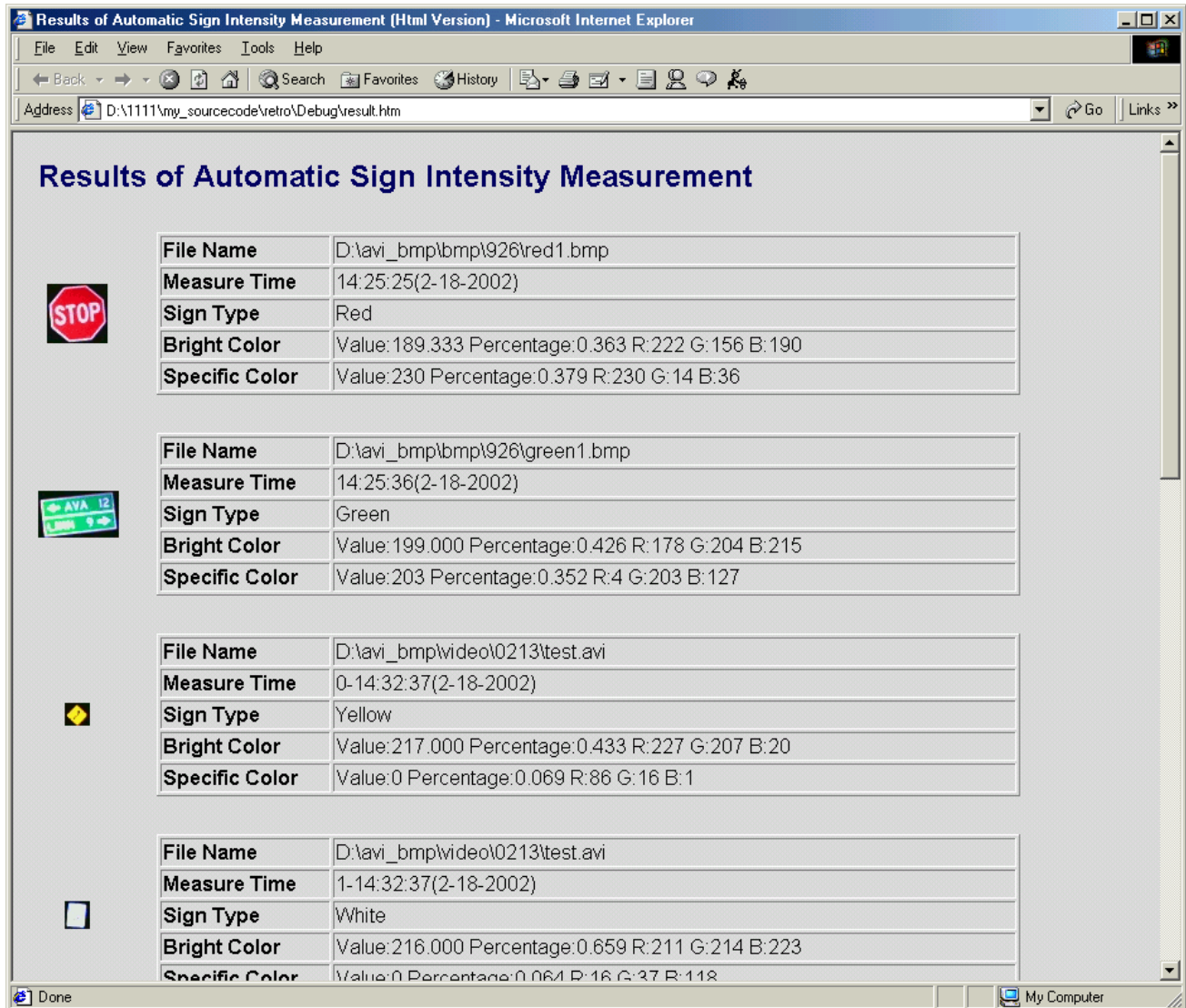
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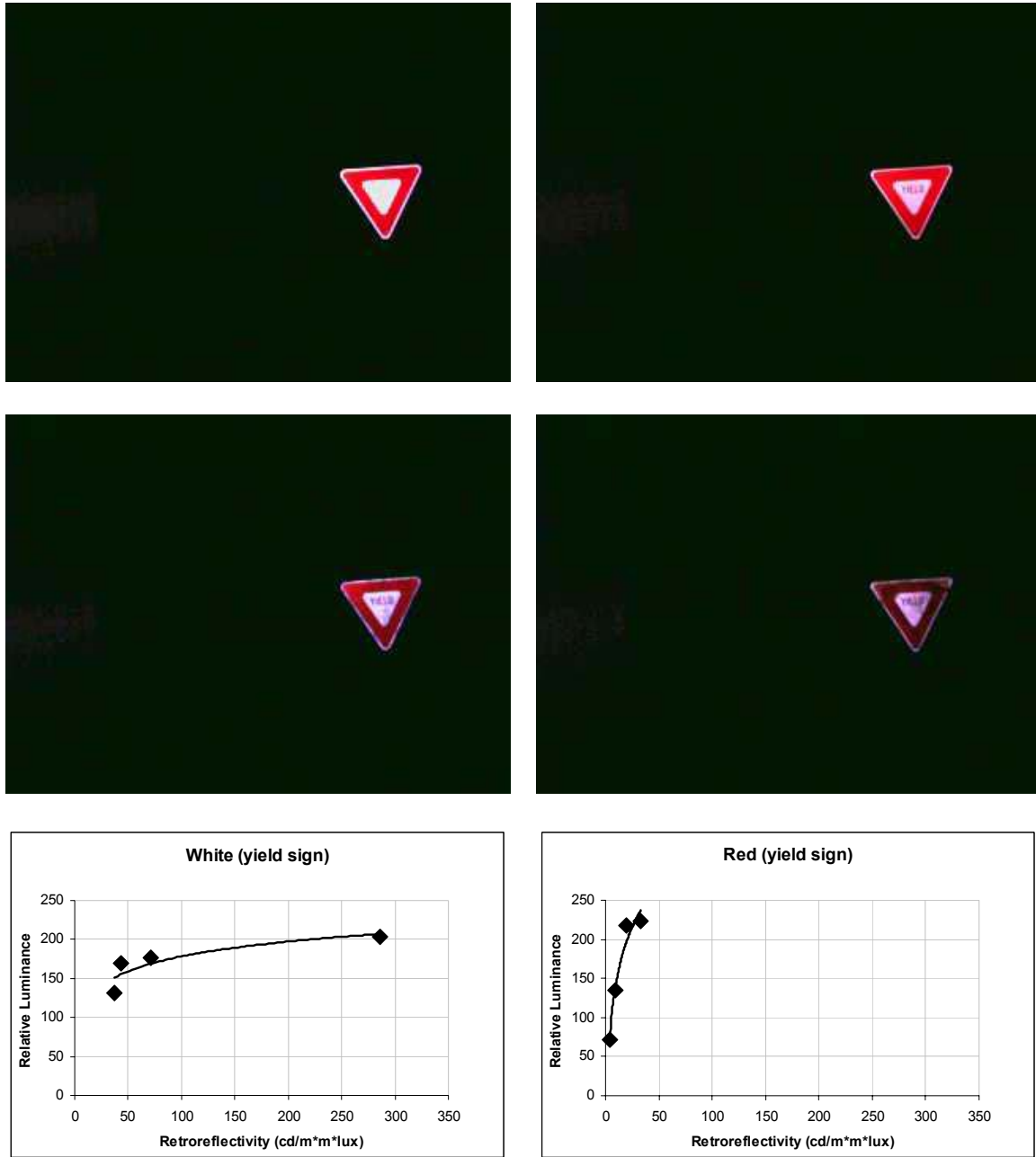
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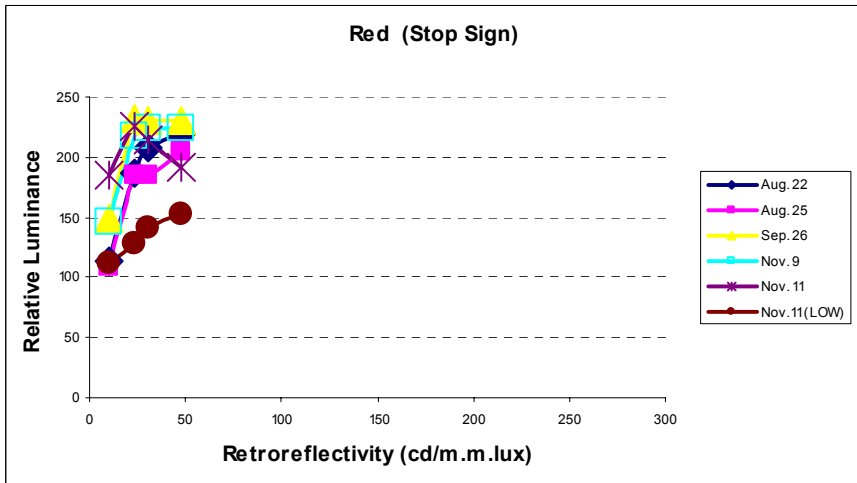
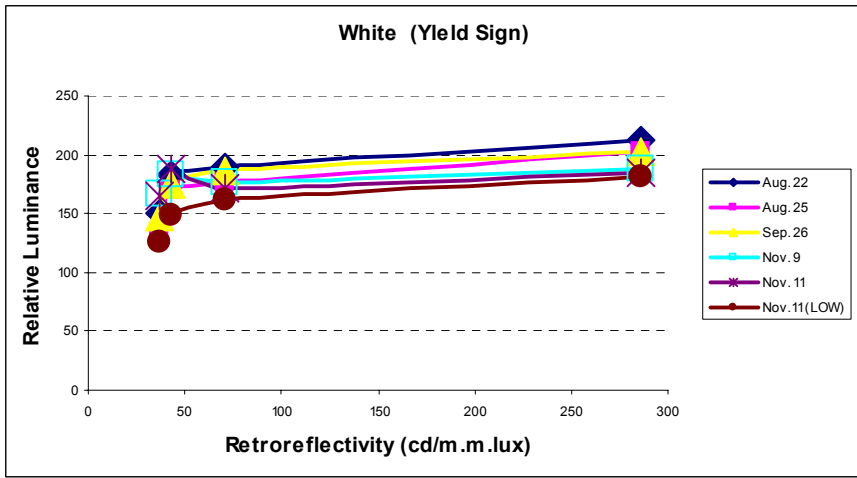
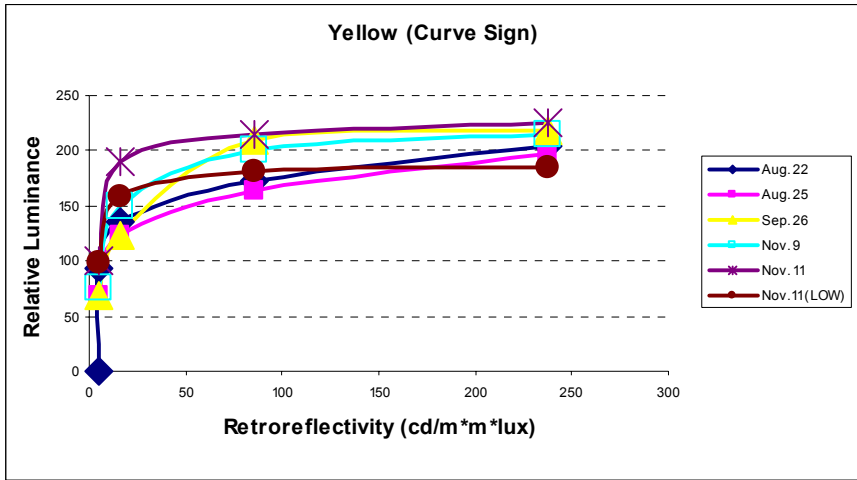


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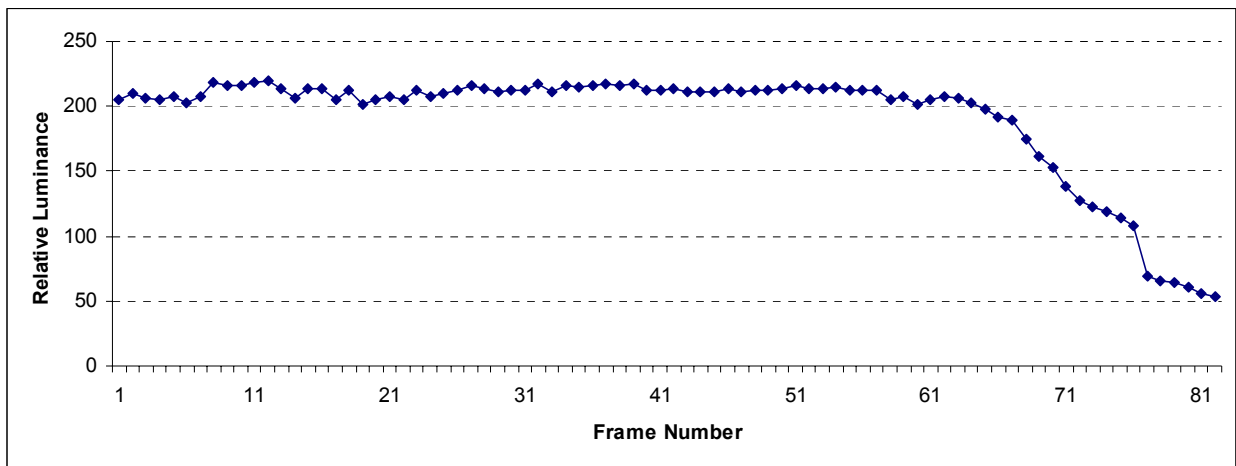
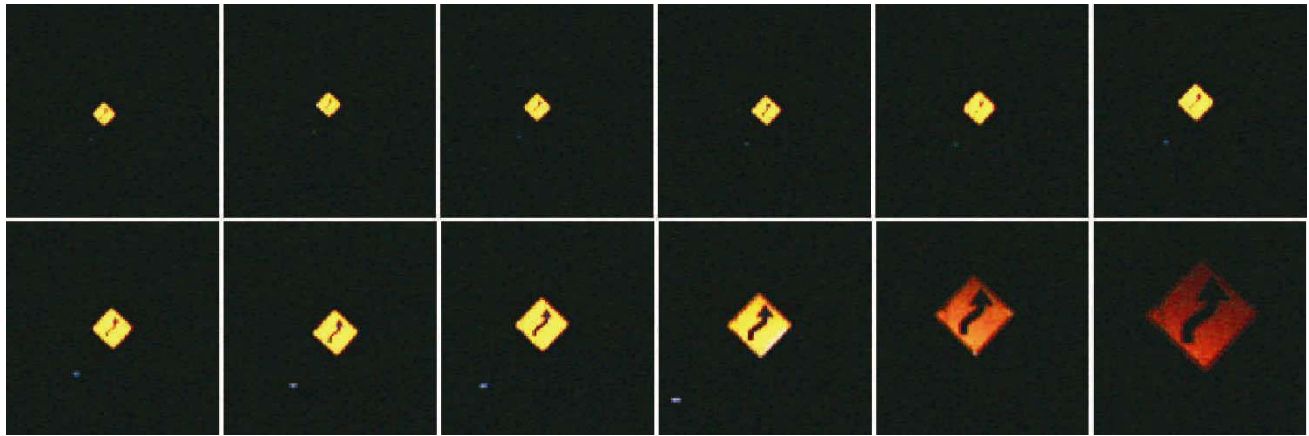




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