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AUTOMATED MOBILE HIGHWAY SIGN RETROREFLECTIVITY MEASUREMENT

QIANG NIU
University of Missouri-Rolla, Rolla, Missouri, USA
FIKRET ERCAL
University of Missouri-Rolla, Rolla, Missouri, USA

NORBERT H. MAERZ
University of Missouri-Rolla, Rolla, Missouri, USA

ABSTRACT

This paper presents a mobile image-based system for measuring the brightness of highway signs at night time, so that visibility standards for signs can be evaluated and maintained to protect the safety of the motoring public. The system is composed of a high speed IEEE-1394 digital camera, and a laptop computer with a purpose-designed measuring software, which is composed of three modules: 1) Image and video processing; 2) Image analysis; and, 3) Data storage. Using vehicle headlamps as an illumination source, the system can acquire, classify, and analyze the visibility of the traffic signs in real time, and report results to a data file. The analysis algorithms, including elements of sign isolation, classification, and intensity measurement, are designed for easy implementation and fast real-time measurement. The results of static testing experiments on signs, and on-road real-time measurements are described in this paper and they show the feasibility of such a system.

INTRODUCTION

For highway signs to accompolish their intended purpose, which is to promote highway safety and efficiency, they must be visible to motorists. At night, the visibility of the signs depends on the retroreflectivity of the sheeting materials on the signs. This paper presents a mobile image-based measuring system for measuring the brightness of highway signs at night time, so that visibility standards for signs can be evaluated and maintained to protect the safety of the motoring public.

Signs must be legible and color distinguishable at night as well as day. While this can be accomplished through external illumination of the signs, retroreflection is the most commonly used means of making signs visible to the driver at night (Black, et al, 1992). When illuminated by external lighting sources such as automotive headlamps, traffic signs appear bright in proportion to their ability to redirect the incident illumination back toward the driver. The term luminance is used to quantify the amount of light that is redirected by the sign (Paniati, et al, 1993). So luminance is “what the motorist actually sees”. Retroreflectivity is a term used to describe the amount of light reflected from retroreflective materials. It is measured in terms of the coefficient of retroreflection, R_a, which is the quotient of illuminance to the retroreflecting surface’s area (Paniati, et al, 1993). R_a is measured in units of candelas per foot candle per square foot (cd/fc/ft^2) or the metric equivalent, candelas per lux per square meter (cd/lux/m^2).

Currently, measuring sign retroreflectivity in the field requires the use of a portable hand-held retroreflectometer, although sheeting material and new signs can be measured in a more accurate laboratory setting. While it is a portable unit, it is still too cumbersome and time consuming to be used for a wide scale inspection program. A mobile retroreflectometer is currently under development by the FHWA. It requires a laser range finder, a second operator, and electronic strobes, and results in significantly higher capital and maintenance costs.

Road sign recognition (RSR) is a field of applied computer vision research concerned with the automatic classification of traffic signs in traffic scene images acquired from a moving vehicle (Paclik). A literature review has revealed that a significant number of papers deal with automated road sign recognition under daylight conditions, but very few papers deal with RSR at nighttime, only one paper proposes a mobile system.

SYSTEM OVERVIEW

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 road signs in real time, and reports results to a data file.

Hardware

The system makes use of a color digital video camera, a laptop computer, and a high speed IEEE 1394 (Firewire$^{®}$, i.LINK$^{®}$) digital connectivity to bring images from the camera to the computer in real time. In this research, a SONY DFW-V500 camera was selected and conneted to a SONY PCG-FX190 laptop with an IEEE-1394 Fireware cable (6-pin to 4-pin), and was mounted on the front dash of a GMC truck with a mounting bracket, as shown in Fig. 1.

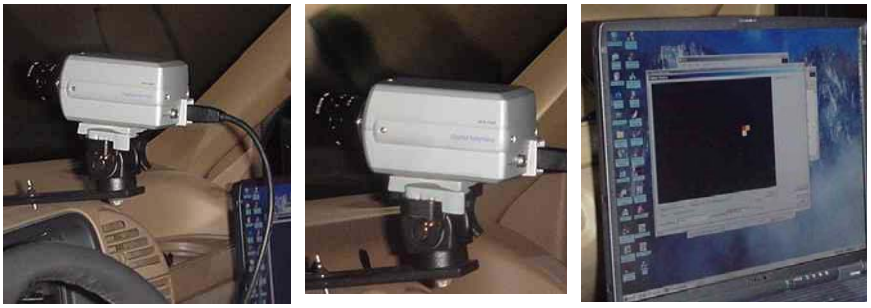

Figure 1. Camera Mount and Connection to Laptop Computer

Software Components

Software development was considered to be the most important part of this application. Microsoft Foundation Classes® (MFC) and C/C++ were used as developing languages; Microsoft® DirectShow®, COM® (Component Object Model), WIN32® as the core APIs. Image processing and analysis algorithms were developed in-house, and integrated under the Microsoft Visual C++® environment in a 32-bit Microsoft Windows® Operating System.

The software system architecture is shown in Fig. 2. It contains three modules: Image and video processing; image analysis; and, data storage. Image and video processing includes video capture (digital image acquisition) and image data buffer processing (image buffer extraction and storage). Image analysis includes traffic sign detection, sign classification, and sign intensity measurement. Data storage includes storing analyzed results to TXT files, converting TXT files to HTML files, etc.

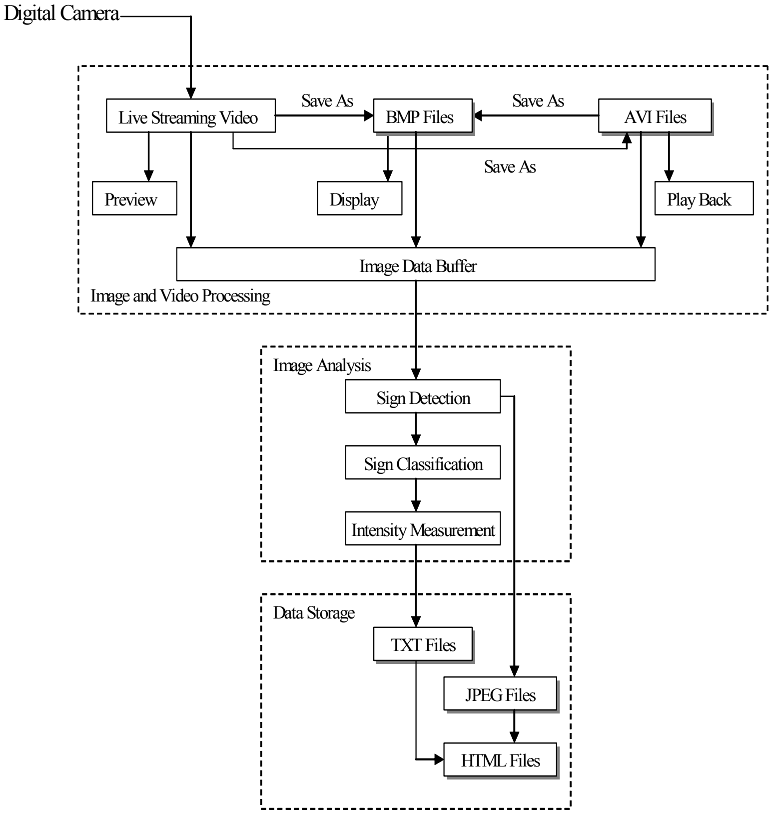

Figure 2. Software System Architecture Diagram

IMAGE AND VIDEO PROCESSING

Digital image processing concerns the transformation of an image to digital format and its manipulation by digital computers. Video capture and image data buffer processing of this research are presented in this paper.

Video Capture

Video capture is the process of acquiring a digital image. It is the first step in any digital image processing application. Using the digital camera and Fireware connectivity, the optical signal can be directly transformed to a digital one.

With the capture graph and capture filter supplied by DirectShow and Microsoft Windows Driver Model® (WDM), which was designed to resolve the problems inherent in the Video for Windows® architecture, Microsoft provides a powerful software environment for developers to build portable image applications almost independent of internal/external devices, so it is possible to preview live video, capture live video as AVI (Audio Video Interleave) files, save the buffer of the live video as BMP files, use captured data to do real time analysis, etc. A C++ class called CGCap was implemented in this research to capture video.

Image Data Buffer Processing

The image data buffer is a temporary storage location for image information being sent, received or analyzed. It contains the actual color information and it is stored in a color-index array. In this study, the image data buffer used for digital image analysis was obtained from three sources: live video stream, AVI files, BMP files; live video was stored to AVI files and BMP files. The video sequences, such as live video stream and AVI files, are actually sequences of static images that are displayed continuously. Hence, the color system of image data buffer chosen in this study is RGB (Red, Green, Blue).

IMAGE ANALYSIS

In order to measure the intensity, the individual signs must be detected/isolated, classified, and measured from the image data buffer, which could be obtained from static images (BMP files) and video sequences (live video streams and AVI files).

Sign Detection

Each image, while in the image data buffer, is checked for the substantial presence of a sign. This part of digital image analysis is called region segmentation, which refers to the decomposition of a scene into its similar components. For this study, the target sign needs to be detected and isolated from the given image. It is a key step in the analysis.

A **Region Growing Algorithm** was used in this study. It is an image processing method that segments a digital image into similar regions based on the color values of the pixels. It has been used mostly in the analysis of grayscale images; however, some significant work has been completed in the color realm by Tremeau et al. (1997).

The region growing algorithm used in this application 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 (Marshall, 1997). The algorithm starts with a seed pixel, examines local pixels around it, determines the most similar one, which is then included in the region if it meets the certain criteria. This process is followed until no more pixels can be added. It is presented as follows:

1. Select a seed pixel within the image and compare it with neighboring pixels;
2. Region is grown from the seed pixel by adding in neighboring pixels that are similar, increasing the size of the region;
3. Each pixel in the image receives a label from the region growing process; pixels will have the same label ID if and only if they belong to the same region;
4. When the growth of one region stops we simply choose another seed pixel which does not yet belong to any region and start again.

This whole process is finished until all pixels are examined.

Sign Classification

After the segmentation of image, the isolated sign needs to be classified. There are many different methods to classify the signs, such as color-based or shape-based detection and recognition described in the literature review. For the current stage of the research, only color-based recognition was used for the sign classification.

From the Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2001), there are in total 7 kinds of signs by colors: blue, brown, green, orange, red, yellow, and white, so the target signs can be identified in terms of colors. These were used both for classification and measurement.

These colors divide into three groups:

- The **“Dull” color** is defined by each of the Red, Green, and Blue (R, G, B) buffer values being all less than 50 (on a scale of 0-255). These values are considered so low that they cannot be effectively measured. It is nominally black and has nominally zero retroreflectivity.

- A **“Bright” color** is defined by R, G, B values all greater than 50. It consists of white, yellow, or orange, which are highly retroreflective sign colors.

- A **“Specific” color** is defined by any combination of R, G, B values where at least one color is above 50 and another below 50. It consists of red, green, blue, or brown colors, which are the lower retroreflective colors comparing the background of many of the signs.

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:

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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 and G) and $R>75$, it is red sign,
    Else if the specific color's $B >>$ (R and G) and $B>75$, it is blue sign,
    Else if the specific color's $G >>$ (R and B) and $G>75$, it is green sign,
    Else it is brown sign.
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The criteria values above are based on the experiments, and the correctness of the classification for this research purpose (using high beams and specified camera properties) is more than 95%.

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

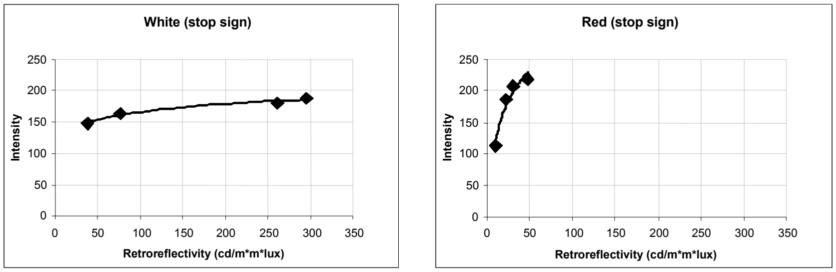
DATA STORAGE

In order to permanently store the results of the analysis, including the results of the real time video analysis, the stored AVI files analysis, and the stored bitmap files analysis, the identical file structure was used to create a data storage subsystem. The analyzed data can be saved as plain text (*.TXT) file or hypertext markup language (*.HTML) file format with small embedded detected target signs.

SYSTEM TESTING AND EXPERIMENTS

In addition to testing the measurement system components individually, the system was also tested as a whole. Static testing experiments on signs, and on-road real-time measurements were conducted. The relationship between the measured brightness of the signs with retroreflectivity and dynamic testing was determined after the experiments.

The purpose of the static studies was to demonstrate the measurement in static testing range and from static BMP image file. The static studies involved measuring the retroreflectivity of the signs using a hand-held retroreflectometer; measuring the brightness of these signs using the measuring software; and, finding the relationship between the measured retroreflectivity and measured brightness. Some results are shown in Fig. 3.



White (stop sign)

Red (stop sign)

Figure 3. Red (Stop) Signs

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. The user interface is shown in Fig 4.

The real-time measurements were the on-road experiments done at night time. When the vehicle was proceeding along the roadway at highway speeds, the measuring software was measuring the brightness of the target traffic signs. Because the same sign appears 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.

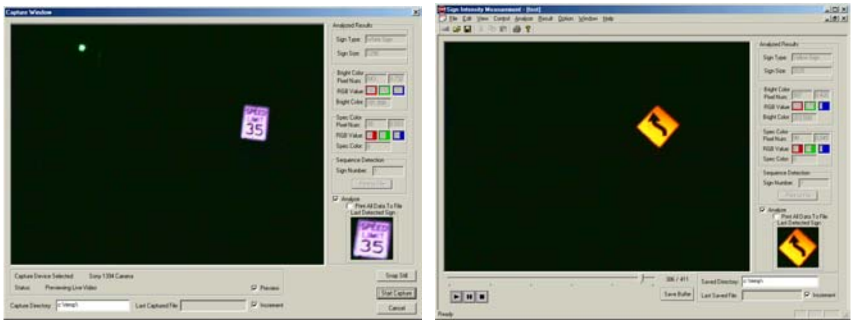
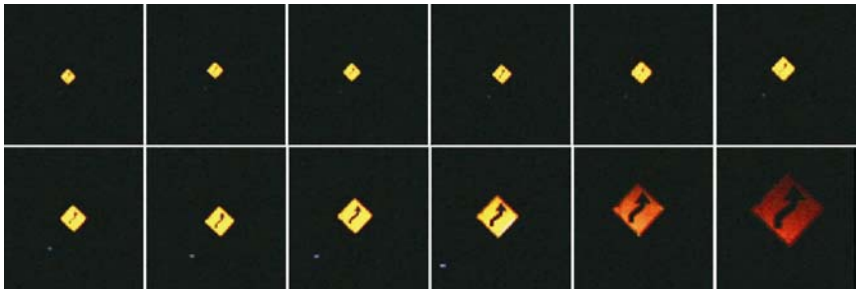


Figure 4. Measuring Software User Interface for Live Streaming Video and for Recorded avi Files.

Fig. 5 shows an example of this relationship, reproduced at a rate of 10 frames per second. The top of the figure shows the video sequence of a single yellow sign imaged along highway, and it was analyzed about every 8th frame. The bottom of it shows the brightness measurement of that yellow sign as a function of analyzed frame number. Each frame shows a successively closer image of the sign.



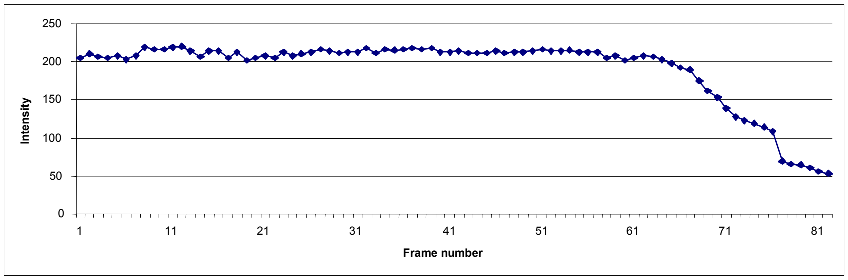


Figure 5. Video Sequence and Brightness Measurement of a Yellow Sign

CONCLUSIONS

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

1. The concept of using a mobile vision-based measuring system to classify and to measure the visibility of road signs was 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 human eyes see when looking at signs, incorporating the normal illumination provided by the headlights of vehicles, 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 measurement can be made in real time at highway speeds and produces a record that includes a small thumbnail image of the sign as well as the measured data and could easily to be tied to GPS position information.
5. Retroreflectivity and measured intensity can be correlated, but only within the same color. The “bright” colors (yellow, white and orange) show high retroreflectivity, and large variability in retroreflecitvity but small changes in brightness. The “specific” colors (red, green, blue, and brown) show a low retroreflectivity, with low variability in retroreflectivity but large changes in brightness.
6. 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.

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