The Automated Determination of Sign and Pavement Marking Retroreflectivity from a Moving Platform

Mandli Communications, Inc.
<address>
<city>
608-835-3500
www.mandli.com

I. Introduction

Even though only a third of motor vehicle mileage is driven after dark, more than half of all motor vehicle fatalities occur after dark.[1] Safe motor vehicle travel during low light and nighttime conditions requires that directional, regulatory and cautionary information displayed upon traffic control devices be clearly visible to a vehicle operator traveling at a reasonable velocity down a roadway. With over 58 million traffic control devices currently installed in the United States and more being installed all the time, a system for rapidly locating and assessing sign effectiveness, and ordering necessary maintenance activities is essential to assuring compliance to MUTCD reflectance requirements. The Federal Highway Administration (FHWA) estimates that up to one half of the more than 58 million traffic control devices installed on the nation's roadways are beyond their useful life from a reflectivity standpoint. A significant number of traffic control devices are in need of maintenance.[2]

Generally, highway and street maintenance departments do not systematically evaluate the deterioration of the reflective materials used on road signs and markers. If inspections of road signs or markers are performed, they are typically accomplished by having inspectors manually position a handheld retroreflectometer directly on the surface of a sign in order to determine a single retroreflectivity value for that sign. When there are a large number of traffic control devices in a given jurisdiction, the task of manually inspecting all of these road signs and markers can be time consuming and expensive.

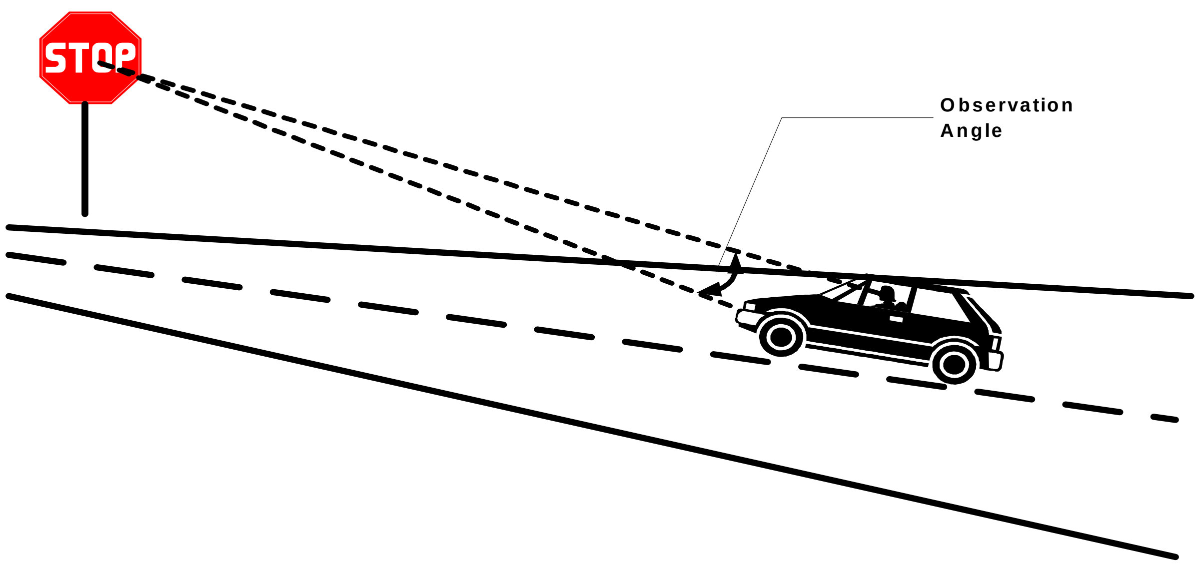
This paper will review the accepted critical parameters for evaluating sign and pavement marking functional effectiveness, summarize current methods for evaluating these parameters, and describe how RetroView™ systems significantly enhance traffic control device asset management.

II. Background

Various kinds of reflective sheeting, decals and paints are used on road signs and markers to enhance the readability and perception of information displayed during low light and nighttime conditions. Unfortunately, the effectiveness of these reflective materials tends to deteriorate over time. Retroreflectivity (defined as the ability of a material to reflect incident light back towards its source), specified in candelas per lux per square meter ($cd/lux/m^2$), is an important characteristic utilized by transportation agencies to assess the nighttime visibility of road signs.

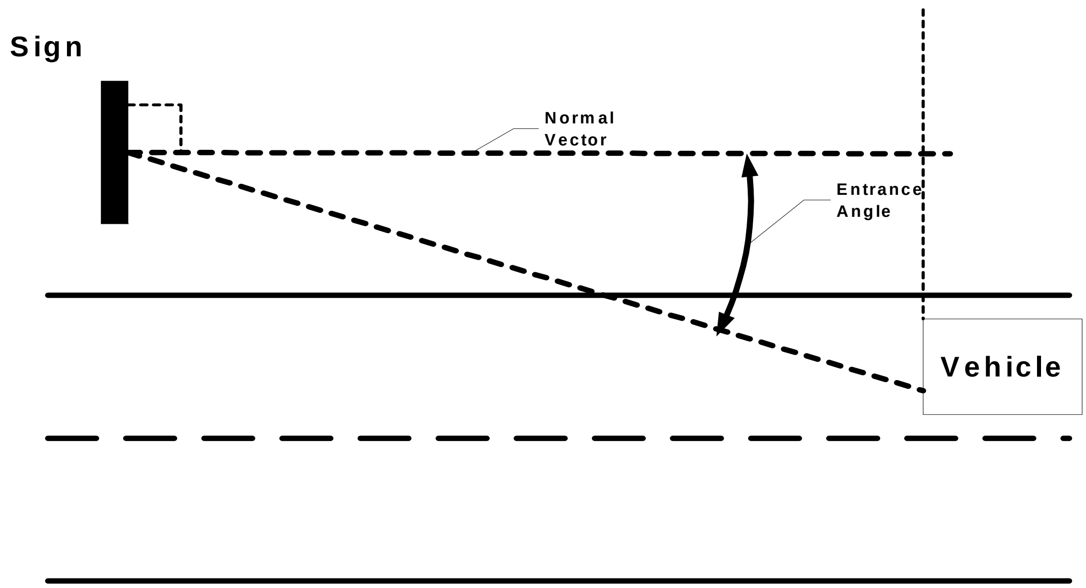
Sign retroreflectivity (R_A), varies according to two key parameters, observation angle and entrance angle. The observation angle (See Fig. 1) is the angular displacement between a light source and a light sensor, as measured from an object face surface. In the case of a vehicle moving along a highway, the observation angle is defined by the distance of the vehicle from a sign face surface, the placement of the light source (headlights) on the vehicle, and the position of the light sensor (eyes of the vehicle operator).

Figure 1 - Observation Angle Description

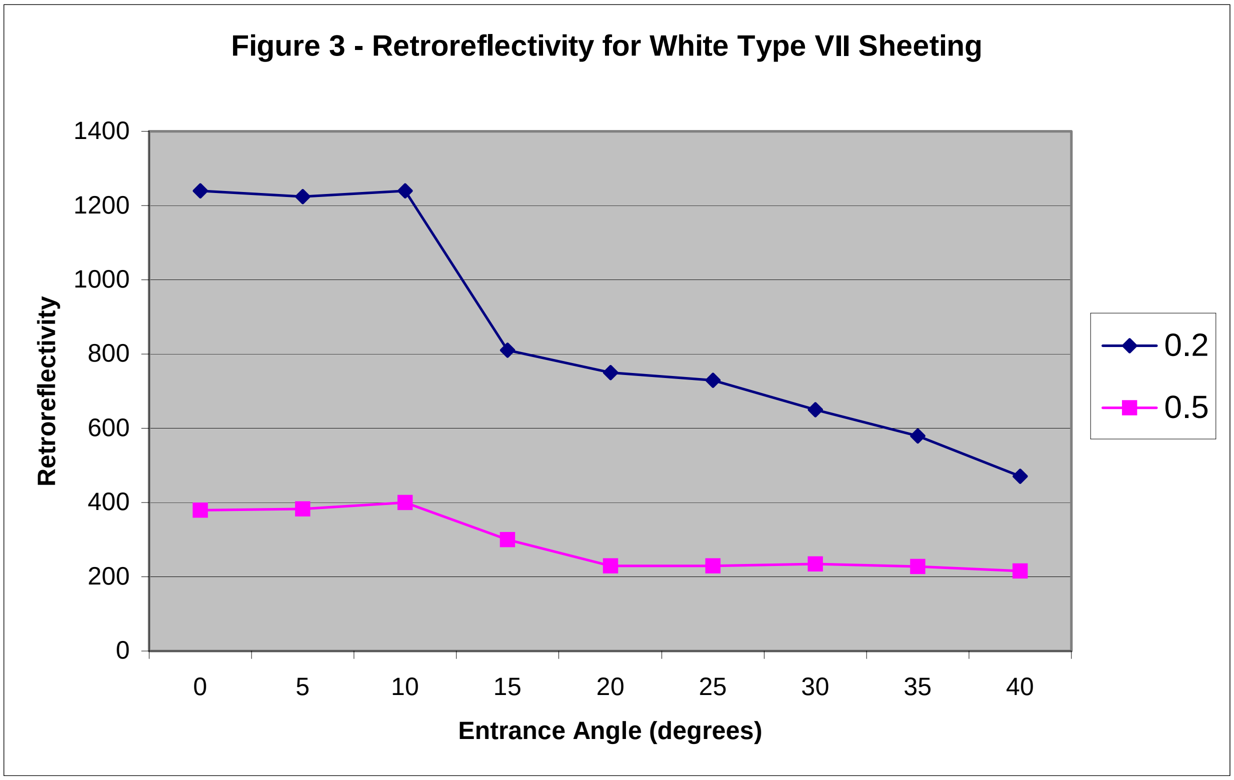


The entrance angle (See Fig. 2) is defined as the angular displacement of the incident light relative to the normal vector from the object face surface. Entrance angles are impacted by the angular position of a sign relative to the highway, the sign's lateral distance from the highway, and the distance of the vehicle from the sign.

Figure 2 - Entrance Angle Description



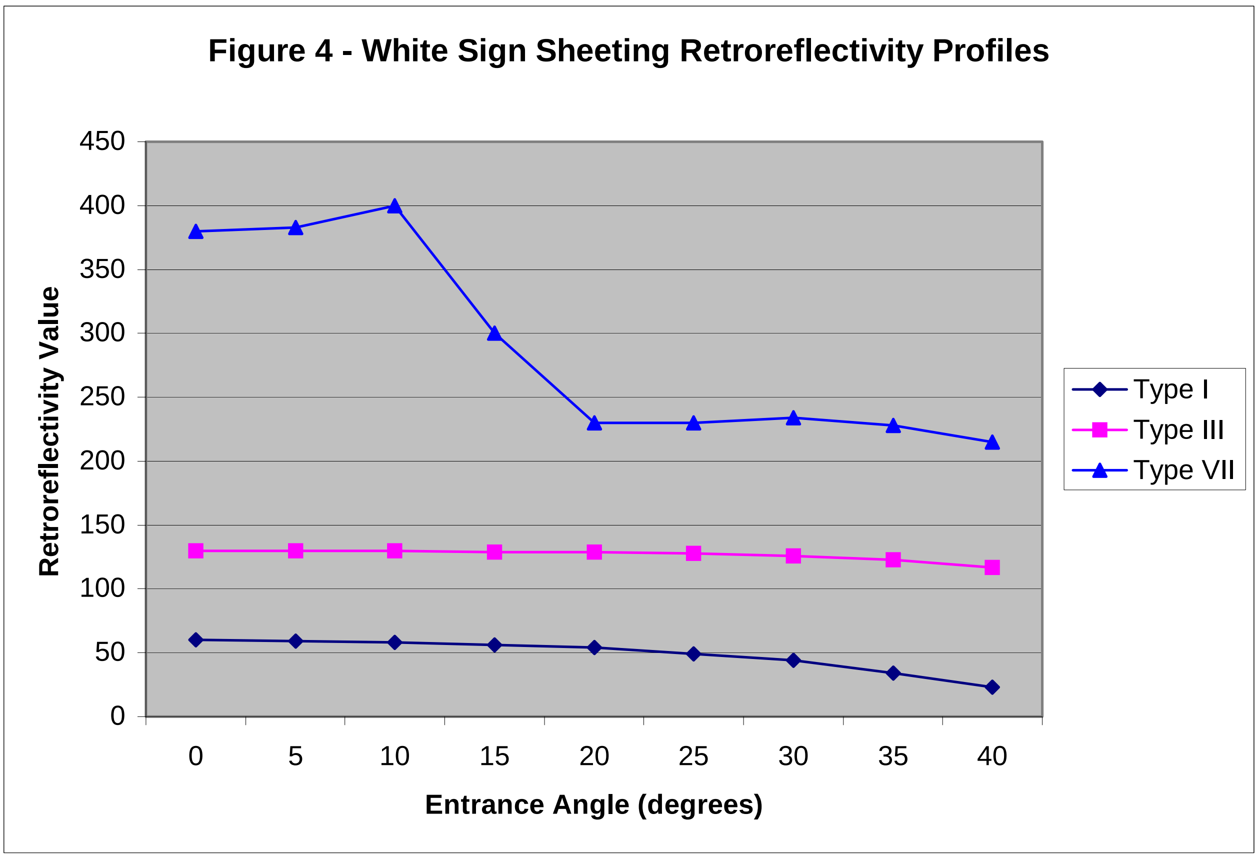
As the entrance angle and observation angles increase, the retroreflectivity of a sign decreases accordingly. Figure 3 below shows the R_A values for Type VII sheeting at two observation angles (0.2 and 0.5 degrees) over a range of entrance angles from 0 degrees to 40 degrees. Note how the R_A values decrease as the entrance angles increase.



Factors that cause increased entrance angles are: 1)placing signs further from the edge of the roadway, 2)increasing the width of the shoulder, 3)operating vehicles that are not in lanes adjacent to the sign, and 4)rotation of the sign face slightly away from the direction of oncoming traffic.

Notice the dramatic impact that observation angle has on R_A in Figure 3. An observation angle of 0.2° may define the geometry of a typical passenger car, while 0.5° may define the geometry of a typical semi truck.

Manufacturers of sign sheeting material have different types of sign sheeting depending on the particular needs of a transportation agency. Figure 4 below shows R_A for three different types of white sign sheeting over various entrance angles. Note the dramatic increases in R_A values as we move from Type I to Type III to Type VII. All of the R_A values shown in Figure 4 correspond to an observation angle of 0.5 degrees.



Several factors contribute to the deterioration of retroreflectivity for signs and pavement markings. Transportation agencies are interested in efficient, low-cost, accurate methods for determining the nighttime condition of the assets in their system. Before presenting the new active-sensor approach, we'll discuss the existing methods for determining retroreflectivity for signs and pavement markings.

III. Current Techniques Used for the Determination of Retroreflectivity

Nighttime Condition Assessment

Many agencies use this method for the subjective determination of sign and pavement marking retroreflectivity. Basically, this approach consists of two people traveling over the roadways at night and recording the signs that fail to exhibit the proper level of reflectivity.

Nighttime condition assessments are useful since they don't require any special equipment, don't require specialized training and can usually be performed with in-house personnel. It is a time-proven method that is widely utilized due to its simplicity.

Transportation officials realize the limitation of nighttime condition assessments. The highly subjective method is prone to data entry and judgment errors. The variability of results over time or between different personnel is the largest criticism of this method. Given the previously available alternatives, the nighttime assessment has been a reliable enough method for agencies that can accept the extreme limitations.

Impulse RM for Signs

One technique for determining retroreflectivity which does not require that a retroreflectometer be placed directly on a sign is the use of the "Impulse RM" retro-reflectometer by Laser Technology, Inc. of Englewood, Colorado, USA. In use, handheld devices like the Impulse RM are manually directed toward, or precisely at, a target object and then manually "fired." Once fired, the handheld device bounces a laser beam off the target object and measures the reflected laser energy that is then used to determine a retroreflectivity value.

Sign retroreflectivity (R_A) is usually measured with an Impulse RM that is pointed at the face of a sign at a distance of about 100 feet. The resulting R_A value correlates roughly to a geometry of 0.2/-4 (observation angle and entrance angle), which has become a generally accepted standard geometry in the industry for signs. The handheld device can measure a single R_A value for a single sign, and can only measure either foreground or background R_A with a single measurement.

The user of the handheld device must be stationary – either standing along the side of the road, sitting on top of an all-terrain vehicle that is stopped along the side of the road, or leaning out of a car or truck that is parked on the side of the road. Operators will typically make several measurements for a given sign and will report the average value, the most frequently occurring value, or use some other ill-defined method for manipulating the series of readings. Since operators must hold the device very steady while a measurement is made, there are considerable opportunities to obtain values for objects other than the intended sign. The net result is that R_A measurements made with handheld devices have considerable exposure to error-inducing procedures.

Other than the repeatability problems mentioned above, there are several other drawbacks of hand-held laser devices like the Impulse RM, namely:

- The handheld device can only measure a single color on only one object at a time.
- The determination of retroreflectivity for a given object is valid only for the actual location, or discrete measurement point, along the roadway at which the measurement was made by the human operator.
- In order to validate a measurement made by such devices, the device must be taken back to the precise location where the original measurement was made for a valid comparison of the measurements to be made.
- The crew performing the measurements along the side of a road is continually exposed to serious injury, even when personnel are sitting inside a stationary vehicle.

SMARTS from the Federal Highway Administration

Another technique for determining the nighttime visibility of signs has been introduced by the Federal Highway Administration (FHWA). The Sign Management and Retroreflectivity Tracking System (SMARTS) is a vehicle that contains:

- One high intensity flash source (similar to the Honeywell StrobeGuard™ SG-60 device)
- One color camera
- Two black and white cameras
- A range-sensing device.
- A GPS positioning system

The SMARTS vehicle requires two people - a driver and a system operator - for proper operation. As the SMARTS vehicle travels down the road, the system operator “locks on” to a sign up ahead by rotating the camera and light assembly to point at the sign. At a distance of 60 meters, the system triggers the flash source to illuminate the sign surface, an image of which is captured by one of the black and white cameras. A histogram is produced of the sign’s legend and background that is then used to calculate retroreflectivity. A GPS system stores the location of the vehicle along with the calculated retroreflectivity in a computer database.

The drawbacks of the SMARTS system are:

- Like the Impulse RM, the SMARTS system can only determine retroreflectivity for one sign at a time and can only determine retroreflectivity for the discrete point on the roadway 60 meters from the sign.
- Two people are required to operate the vehicle and measurement system.
- The SMARTS vehicle cannot make retroreflectivity determinations for signs on both sides of the roadway in a single pass over the roadway and does not produce

nighttime sign visibility information for lanes on the roadway not traveled by the vehicle.

- Because the system operator in the SMARTS vehicle must locate and track signs to be measured while the vehicle is in motion, a high level of operational skill is required and the likelihood that a sign will be missed is significant.

Neither the Impulse RM nor the SMARTS system for determining retroreflectivity lend themselves to increased processing throughput so as to more easily manage the monitoring and maintenance of the more 58 million individual TCDs in the United States.

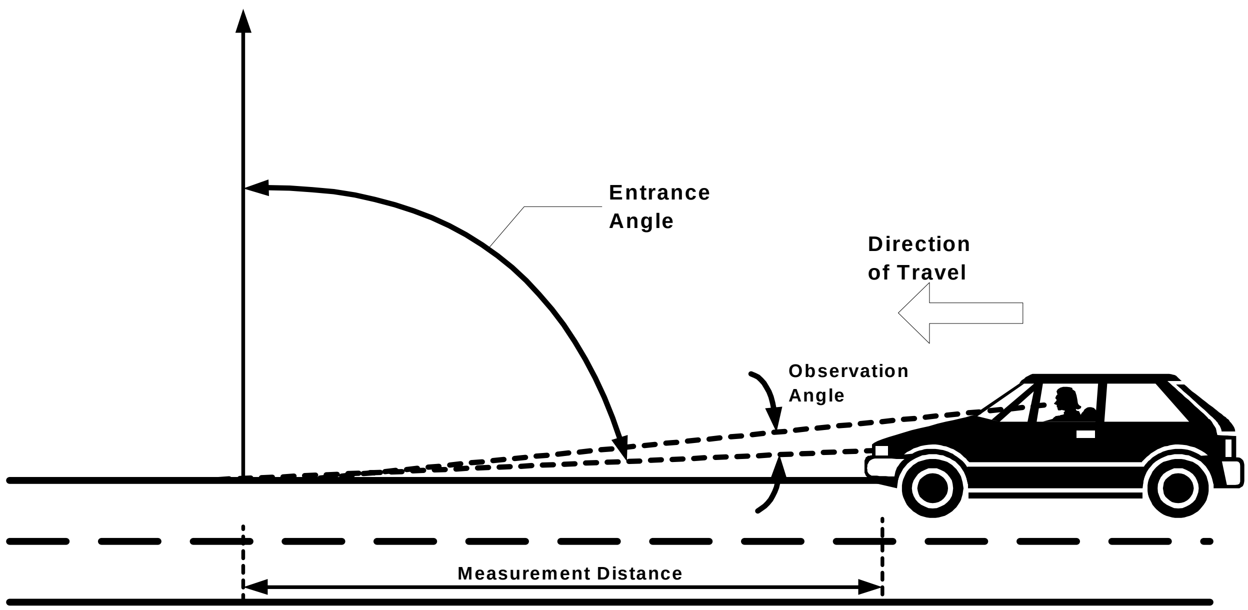
The current so-called automated data collection systems often require that normal traffic be stopped during data collection because either the acquisition vehicle moved very slowly or because the acquisition vehicle had to come to a full stop before recording data about the roadside scene. Furthermore, a human operator is required to point one or more measurement devices at a sign of interest, perform data collection for that particular sign and then set up the device for another particular sign of interest.

With such a large number of traffic control devices that must be monitored, an automated retroreflectivity data collection system is needed that addresses these and other shortcomings of the existing techniques for determining the retroreflectivity of road signs and markers. More automation will enable higher throughput, which is a necessity for the widespread utilization of retroreflectivity measurement systems.

Pavement Markings

The measurement of pavement marking retroreflectivity (R_L) makes use of devices that are somewhat less susceptible to errors than those available for signs. Both the European Committee for Normalization and the American Society for Testing and Materials (ASTM) have standardized on the same R_L geometry of 1.05 degree observation angle, 88.76 degree entrance angle, and 30 meter measurement distance. See Figure 5 below for a graphical description of these parameters for pavement markings.

Figure 5 - Pavement Marking Geometry



Several devices exist that have lasers and associated sensors that are set up with the aforementioned pavement marking geometry. These devices are placed directly on the roadway for stationary measurements or are mounted to the side of moving vehicles for on-the-fly measurements.

Each of the current approaches for measuring R_L suffers from a separate drawback. The handheld devices require personnel to stop at a pavement marking, place the device on the roadway, and make the measurement. If frequent measurements are made, the process becomes time consuming and expensive.

The vehicle-mounted sensors suffer accuracy problems not seen with the hand-held devices. The driver of a vehicle with a mounted sensor must direct the vehicle such that the sensor remains above the pavement markings to be measured. In addition to the near-impossible requirements placed on the driver, the vehicle-mounted laser sensors can only measure pavement markings that are in its direct path. Thus, measuring pavement markings across the entire width of the roadway requires many sensors or, as is usually the case, will leave many markings unmeasured.

Since the patented active sensor RetroView™ measurement system uses a multi-wavelength energy source, it doesn't suffer from the same limitations as the laser-based systems. Information for R_L is gathered at normal traffic speeds for pavement markings across the entire width of the roadway. Accuracy and ease of use are the cornerstones of our R_L approach. Once information is gathered by the capture vehicle, the innovative graphical display tools can be used for planning and maintenance purposes.

Of course, sign and pavement marking retroreflectivity can be determined from the same raw data set. This combined utilization makes for efficiencies never before seen in transportation management. The combination of ease of use, greater accuracy, and innovative graphical planning tools make the RetroView™ approach to retroreflectivity a methodology that can be deployed on a broad scale.

IV. A New Methodology for the Automated Determination of Retroreflectivity

Benefits of the New Methodology

Traditional methods of measuring R_A in the field have been very manual, time-consuming processes. Data accuracy, however, is the biggest hindrance to widespread usage of R_A in sign management.

We took a completely different approach to R_A that will allow its deployment on a broad scale. Our multi-wavelength, active-sensor system is an integral part of the state-of-the-art RetroView™ data collection vehicles. R_A measurements that were traditionally made with handheld devices (used by personnel standing on the side of the road) can now be made by a vehicle that moves at the speed of the surrounding traffic. The benefits of the RetroView™ approach to R_A are:

- R_A values can be determined for multiple points along the roadway for each sign
- R_A values can be determined for multiple signs along the roadway with a single pass of the vehicle
- Digital imagery is captured at the same time as R_A information
- Foreground and background R_A can be determined with the same information
- There is no need to stop the vehicle or drive at less than posted speeds in order to collect R_A information
- R_A values for clusters of signs are determined with a single pass of the vehicle
- Pavement marking retroreflectivity (R_L) can be determined from the same data collection run that is used to gather R_A
- Sign sheeting type can be determined with the same information that is used to compute R_A
- The personnel operating the RetroVire™ vehicle require no prior knowledge of the location or existence of objects for which R_A is desired
- R_A values for all points on a multi-lane roadway can be determined from just a single pass of the RetroView™ capture vehicle

How the New Approach Expands the Usability of Gathered Data

Sign retroreflectivity (R_A) has traditionally been an underutilized aspect of sign management systems. Handheld laser-based devices have made the gathering of R_A values somewhat more attainable. The use of R_A in predictive modeling algorithms has allowed R_A measurements to be utilized in multi-year maintenance programs.

The limitations of today's R_A management have more to do with the definition of the measurement itself. R_A represents a sign's retroreflectivity at a specific point along the roadway (usually 30 meters from the sign) and for a given light source and observer geometry (observation angle). The single value says very little about the sign's nighttime performance: 1) closer to or farther from the sign, 2) in other lanes of travel along the roadway, or 3) at different observation angles.

We found this single R_A value to be too limiting for characterizing a sign's nighttime performance. Fixing this problem required innovation throughout the process – from data gathering to database recording to analysis. The innovative, multi-point data gathering system will be implemented within the high-end RetroView™ capture platforms.

The gathering of multiple R_A points along a roadway requires new ways to display and manage the data. The RetroView™ system will produce a RetroCurve™ for every sign. RetroCurve™ is a graphical representation of R_A versus observation angle. This new method for collecting, producing and reporting as-placed sign behavior will dramatically enhance the value of the resultant sing inventory assessment.

V. How It Works – A Technical Overview

Figure 5 below shows a typical roadway with a traffic sign. It also depicts a path of travel for the capture vehicle and the periodic points at which intensity measurements are made. The active-sensor system works by having a bright, full-spectrum light source flash while an intensity sensor gathers information throughout the field of view. These trigger events occur in synchronized fashion 2-3 times per second as the capture vehicle travels the roadway.[3]

Figure 5 - Reflected Light Intensity Measurements Along a 4-lane Divided Highway

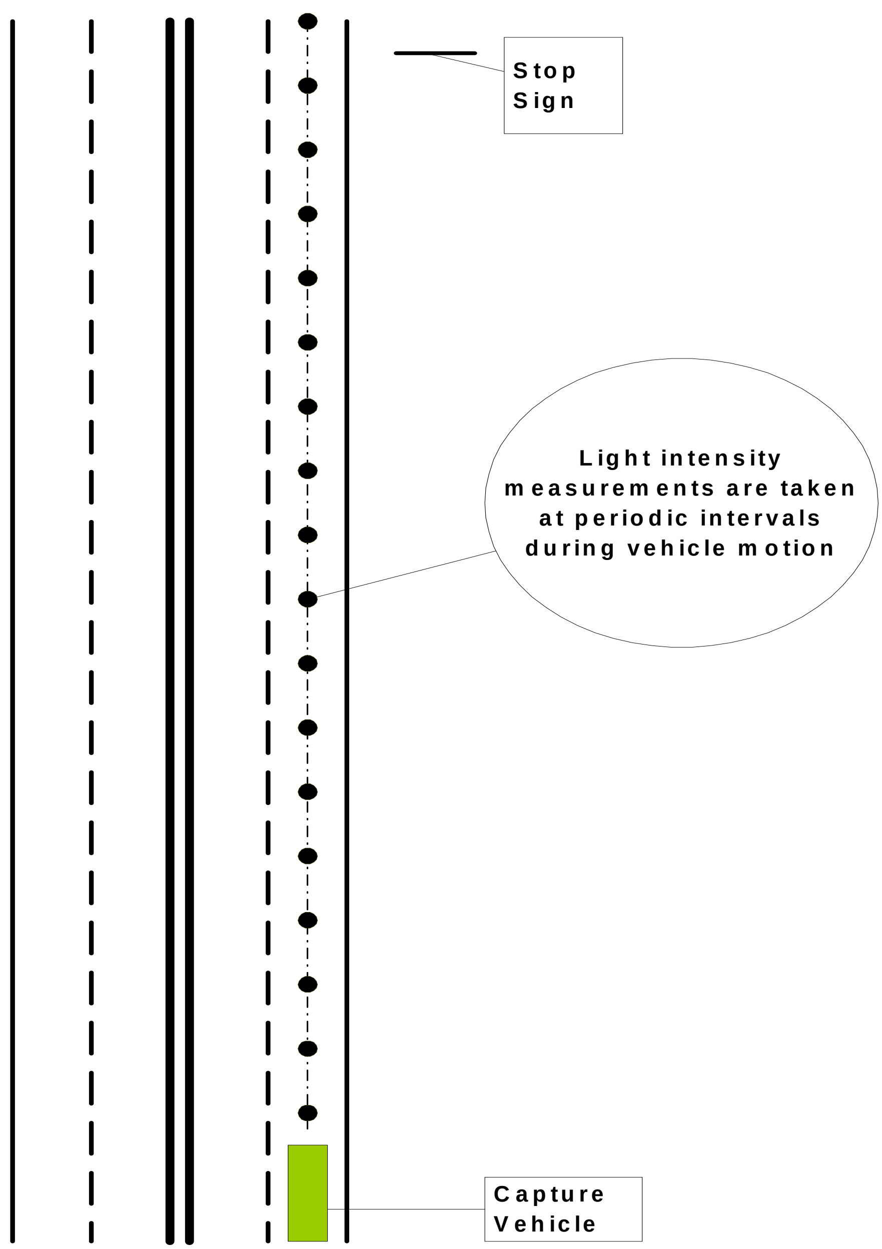
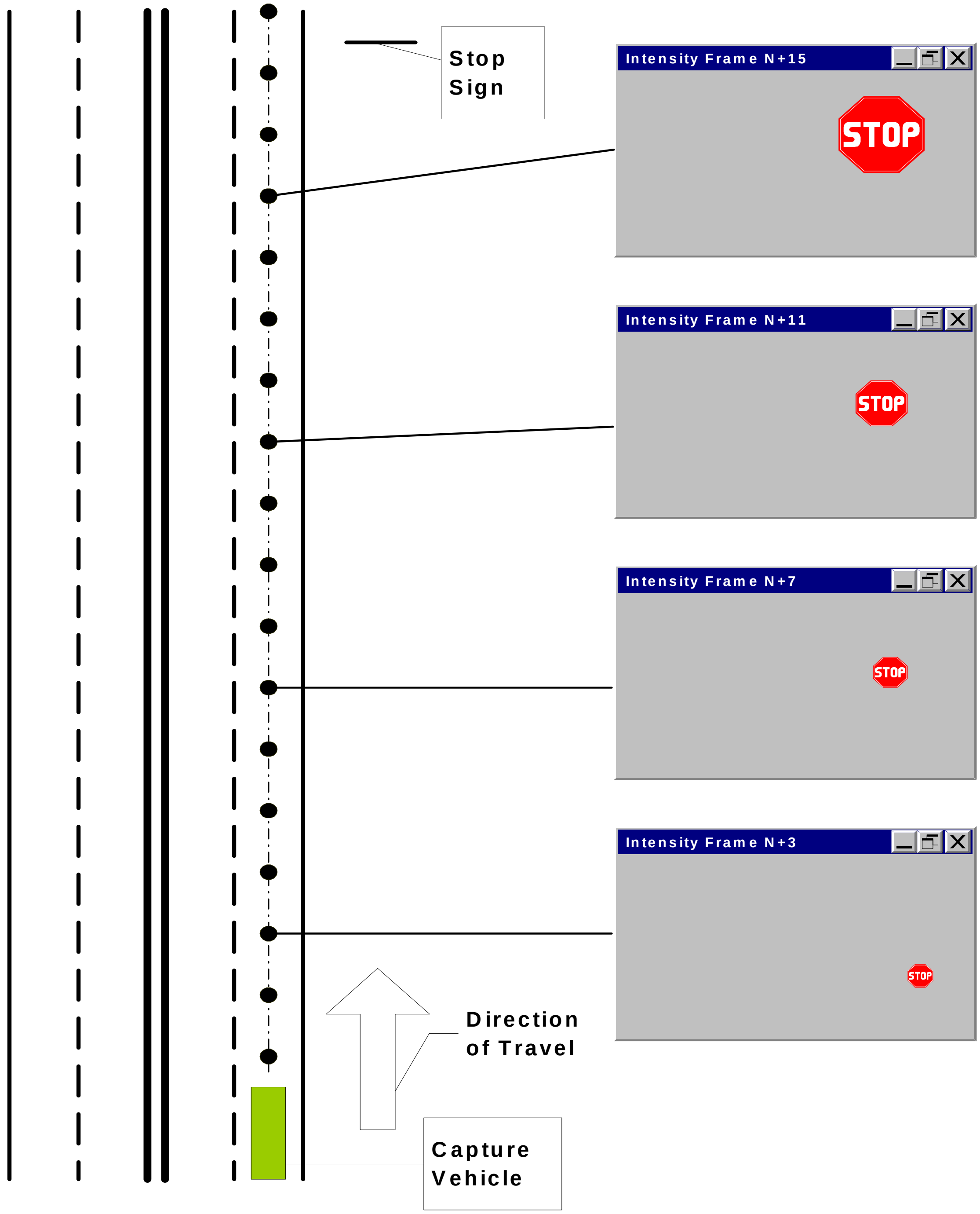


Figure 6 below shows the capture vehicle scenario a bit differently wherein the intensity measurements are actually frames of information captured by a black-and-white digital camera (for greater accuracy, this will be two digital cameras).

Figure 6 - Reflected Light Intensity Frames Along a 4-lane Divided Highway



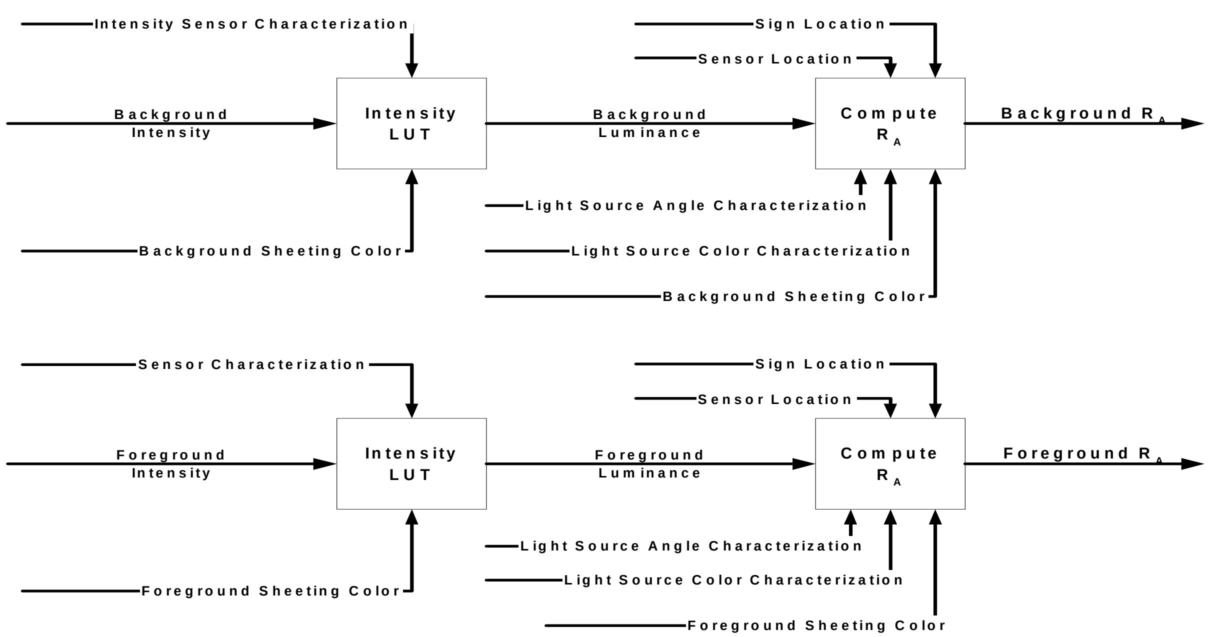
The data capture vehicle simultaneously collects two data streams while driving the roadway:

1. Color imagery collected with at least three forward-facing cameras.
2. Black-and-white imagery collected with one or more cameras that are triggered while a high-intensity light source is flashed.

Both imaging systems are connected to the guidance system on board, which provides precise GPS location, as well as the roll, pitch and yaw for the vehicle. These six degrees of freedom for positional information allow the system to know the precise location and attitude (normal vector) for all of the components of the imaging systems (the color cameras, the b/w intensity sensor(s), and the light source(s)).

Even though the field data is collected in a single pass along the roadway, the post-processing is performed in two passes. The visible object parameters are determined from the color imagery. The retroreflectivity is determined as defined below.

Figure 7 - Determining Retroreflectivity from Light Intensity Measurements



Intensity values alone don't allow us to accurately compute retroreflectivity. We must first use the intensity measurements to compute the luminance values that correspond to the targets identified within the intensity frames. Figure 7 above is a block diagram defining the information required to convert intensity to luminance, and eventually to retroreflectivity.

Converting Intensity to Luminance

Retroreflectivity is not measured directly by the active sensor system. Instead, intensity is measured by the b/w camera(s), is converted to luminance, and is then converted to retroreflectivity. Each b/w intensity sensor (camera) captures over one million pixels for a scene. Each of these pixels is an intensity value within the scene. The capture vehicle continuously flashes the light source and triggers the intensity sensor(s) while driving the roadway, independent of the presence of signs.

The post-processing of intensity information must first identify objects of interest within the intensity frames. Once an object of interest (a sign) is identified, the pixels corresponding to the background and legend intensity are identified. This object is then associated with the same object that was identified in the color imagery stream. Once this association is made, the background and legend colors are known.

According to Figure 7 above, the other piece of information we need to convert intensity to luminance is the intensity sensor characterization. Since the b/w camera(s) will respond differently to various colors of incoming light, the sensor characterization will allow us to accurately convert the intensity value to luminance.

Converting Luminance to Retroreflectivity

Luminance is not a position-sensitive measurement. It is strictly a measure of the radiation entering the sensor. Retroreflectivity, however, depends on the relative geometry of the sensor(s), the incident radiation to the object, and the distance from the object.

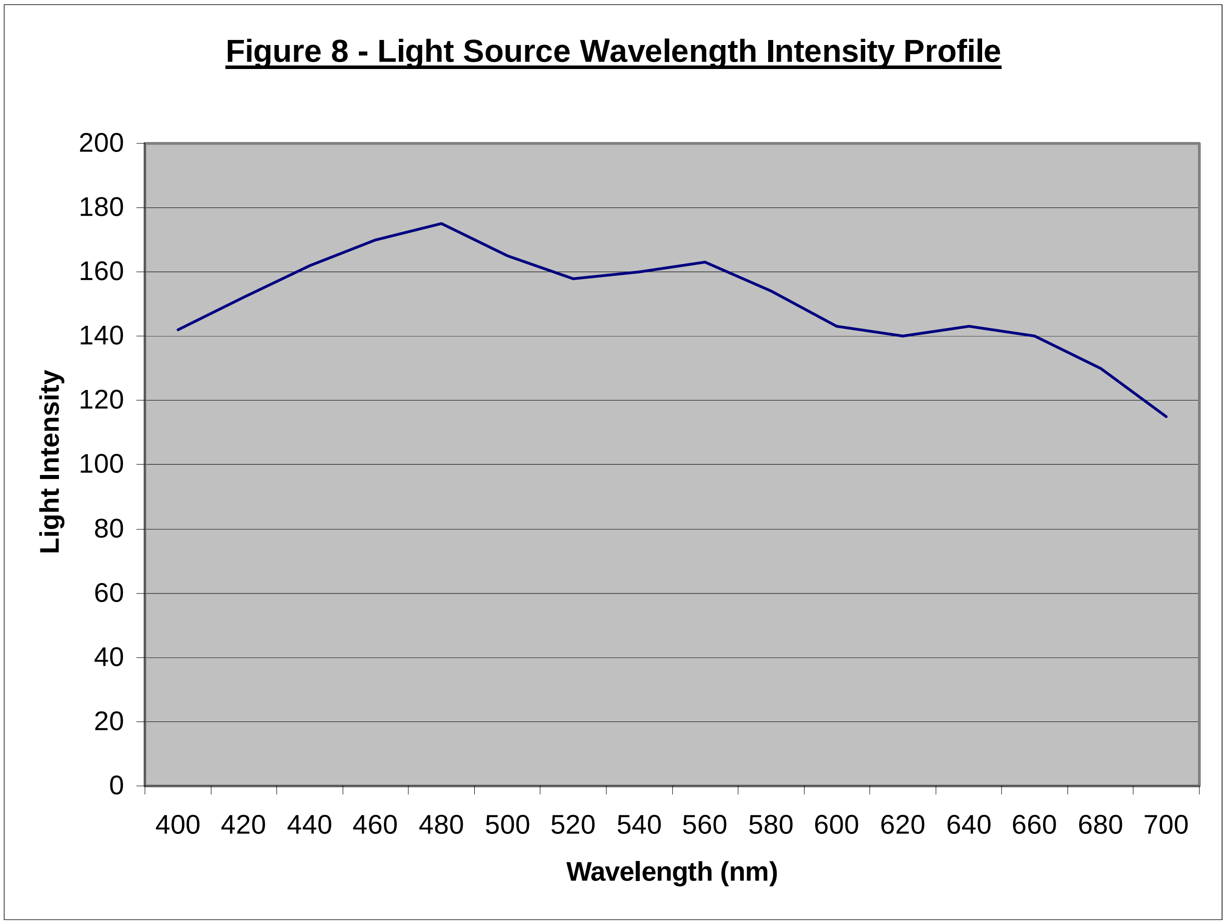
Once we know the luminance of an object (based on the flashing of our light source), we must determine the amount and type of incident radiation (for the sign) that created this luminance. We do this by determining the relative distance and angle between the vehicle (more specifically the light source) and the light sensor(s).

Radiation from the light source is not collimated. The angle characterization of the light source determines the intensity of incident light throughout the field of view of the light source. Also, the light source is not uniform throughout the visible spectrum. Hence, we need to characterize the light source to determine the intensity of the light for each color within the visible spectrum.

The characterization of the light source (both angular and color) is necessary since we don’t point the light source directly at a target.

The desired light source has very high amplitude, a short pulse width, and an even distribution of color output throughout the visible spectrum. In practice, no light source will have uniform color distribution, nor will it have uniform intensity throughout its field of view.

Figure 8 below shows the spectral distribution of a full-spectrum light source throughout the visible spectrum. Note how the intensity values are higher in the blue zone than in the red zone. This spectral output is what is used to create the Light Source Color Characterization in Figure 7.

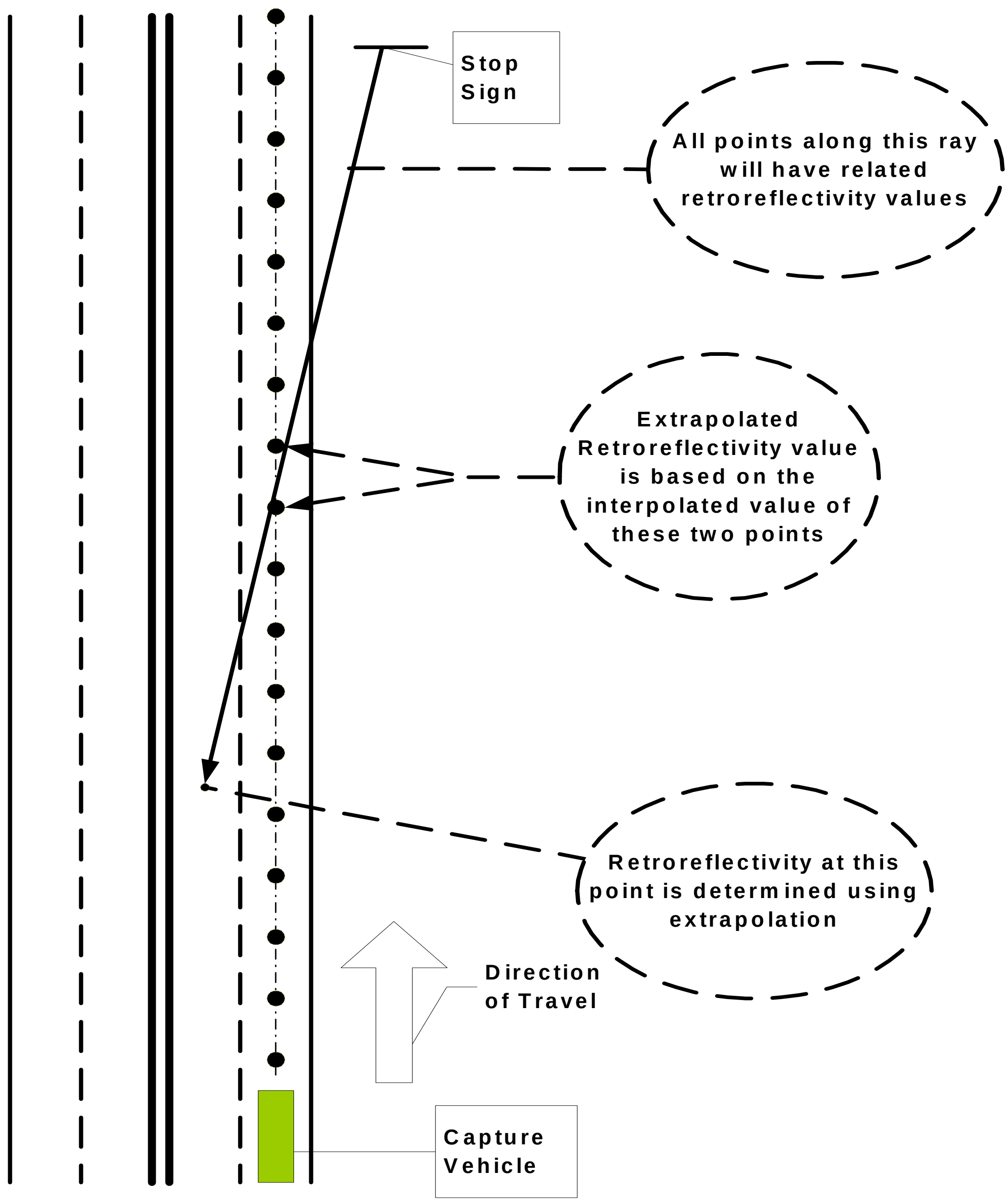


Light intensity from the light source will vary throughout the light's field of view. The characterization of this intensity variation is required since the light source(s) in our system point directly ahead of the vehicle. Hence, we can't guarantee that a certain portion of the light "beam" hits the desired targets. Instead, our Light Source Angle Characterization allows us to know how much incident light hits the targets by utilizing the position of the vehicle and the locations of the identified targets.

Creating a Retroreflectivity Point Cloud

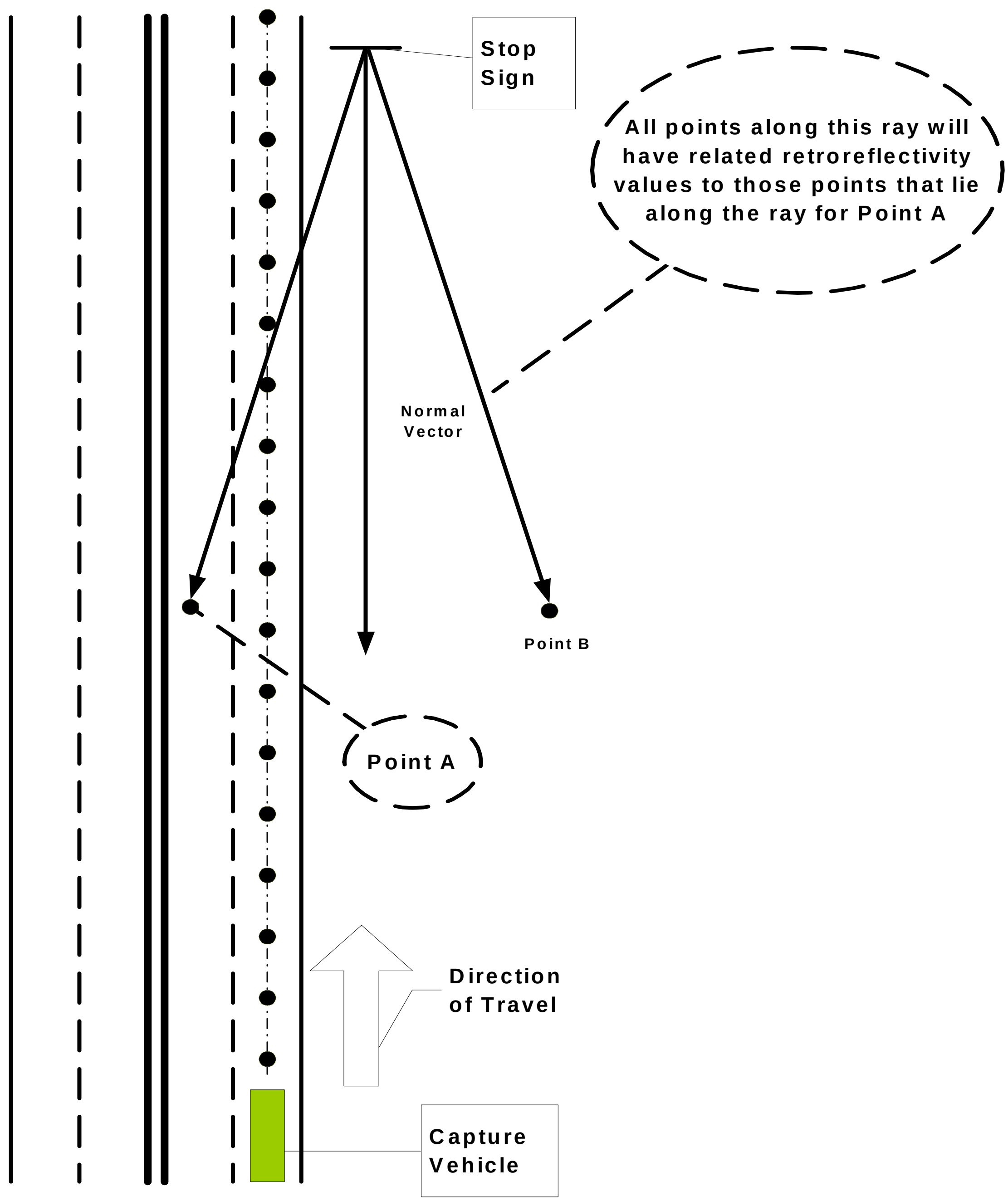
Figure 9 below shows the same four lane divided highway from Figures 5 and 6. This diagram shows how interpolation is used to create intermediate retroreflectivity values and how extrapolation is used to create values for other lanes of traffic. By utilizing these techniques along with the collection of many data points along the roadway, a point cloud of retroreflectivity information can be obtained for an entire roadway.

Figure 9 - Creating a Retroreflectivity Profile Along a 4-lane Divided Highway



The basic retroreflectivity system assumes that the normal vector for a sign is parallel to the direction of travel for a roadway. An optional 2-D laser scanner can be attached to the vehicle that precisely determines the angle of sign (its normal vector). The system proposed herein does not require this laser scanner. Regardless of how the normal vector for the sign is determined, this information can further expand the retroreflectivity point cloud. Figure 10 below shows this process graphically.

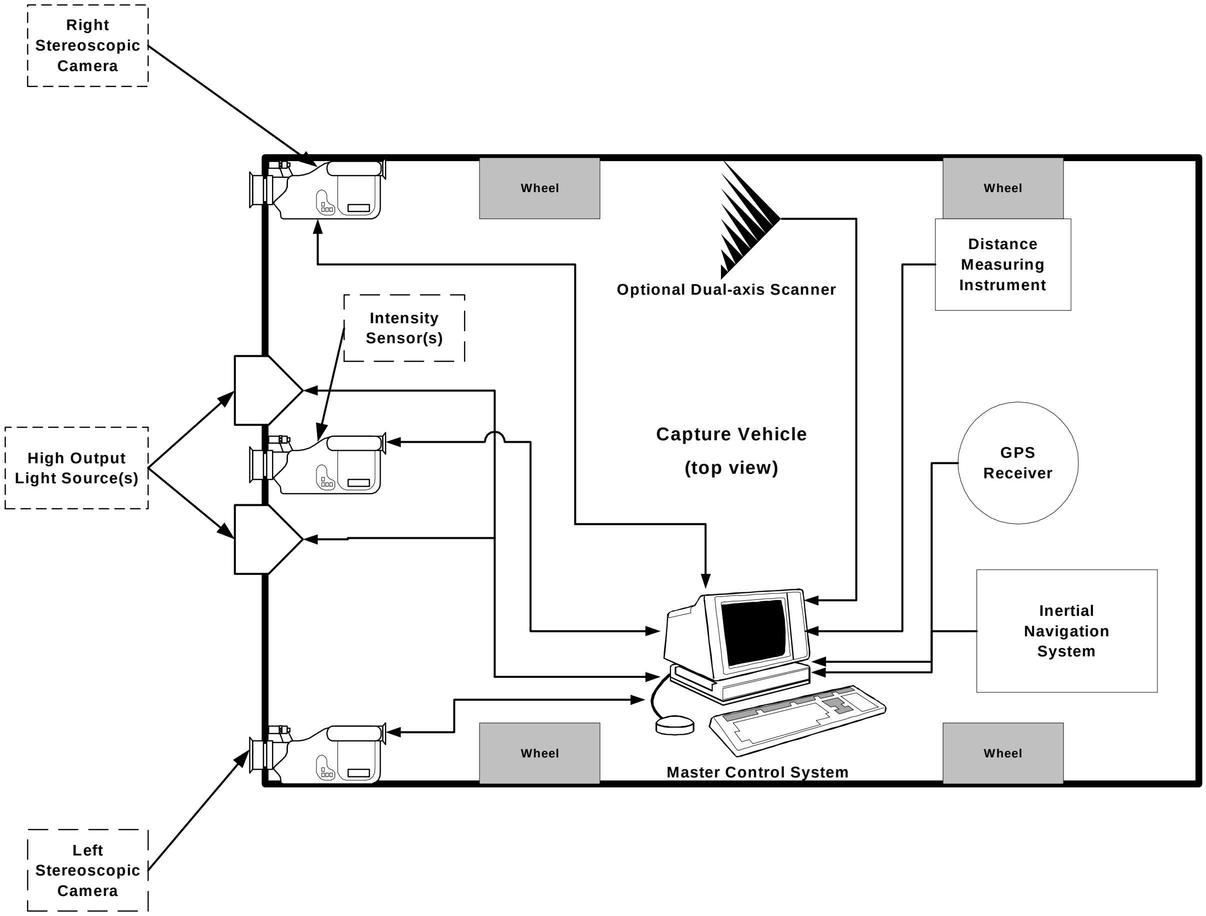
Figure 10 - Using a Sign's Normal Vector to Compute Retroreflectivity



Capture Vehicle System Block Diagram

Figure 11 below shows a block diagram of the capture vehicle with light source(s), intensity sensor(s), color imaging system, vehicle position components, and optional laser scanner.

Figure 11 - Capture Vehicle System Diagram



This diagram shows only one stereoscopic pair of color imaging cameras. In practice, there will be several (from three to six) cameras configured as stereoscopic pairs or as single-camera survey units.

References

1. Kiell, Matthew, “Reflection on a Serious Road Problem”, Traffic Safety, March 1989

2. ITE Traffic Safety Toolbox, “A Primer on Traffic Safety”, 1993.

3. Unites States Patent #6,674,878 - SYSTEM FOR AUTOMATED DETERMINATION OF RETROREFLECTIVITY OF ROAD SIGNS AND OTHER REFLECTIVE OBJECTS.