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Active Safety Roadside Metal Guardrail Surrogate Recommendation

RATIONALE

Reducing road departure crash is one of the primary goals for active safety systems. As more active safety systems, especially road departure mitigation systems (RDMS), are introduced to the market, standard roadside object surrogates are needed for the automotive industry to test and evaluate RDMS systems. SAE International created an Active Safety Roadside Object Surrogate Task Force under the Active Safety Systems Standards Committee to study this topic and recommend roadside object surrogate design guidelines. The Roadside Object Surrogate Task Force's goal is to develop design specifications/requirements for roadside object surrogates. The surrogates should be representative of real roadside objects to the sensors used in RDMS. They can be used for the performance assessment of such in-vehicle sensing systems in real-world test scenarios/conditions. This document summarizes the findings and recommendations from the Roadside Object Surrogate Task Force.

INTRODUCTION

Reducing road departure crashes is one of the primary goals for active safety systems. As more active safety systems, especially road departure mitigation systems (RDMS), are introduced into the market, standard roadside object surrogates are needed for the automotive industry to test and evaluate RDMS systems. SAE International created an Active Safety Roadside Object Surrogate Task Force under the Active Safety Systems Standards Committee to study this topic and recommend design specifications for the roadside object surrogates. All members of the task force are from industry, academia, and government agencies. Many members had experience in using, testing, and/or developing roadside object surrogates. The task force gathered information of metal guardrail surrogates known to the members and analyzed the state-of-the-art features of these surrogates. This document summarizes the findings and recommendations from the Roadside Object Surrogate Task Force.

Since the radar characteristics of metal guardrails depend on their shapes and supporting posts/blocks that vary in different countries, this Task Force adopts the metal guardrail in the United States of America to develop the specifications of the surrogate metal guardrail. These SAE metal guardrail surrogate specifications are representative of 180-degree approach angles. Metal guardrail surrogates for other countries may be developed similarly.

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1. SCOPE

The scope of this document is to provide the design specifications/requirements for metal guardrail surrogates that represent real metal guardrails to the in-vehicle sensors and can be used for performance assessment of such in-vehicle sensing systems in real-world test scenarios/conditions. This document only includes the recommended metal guardrail surrogate characteristics for automotive cameras, LiDARs, and/or radars.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

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3. DEFINITIONS

ACTIVE SAFETY SYSTEM: Vehicle safety systems that sense and monitor conditions inside and outside the vehicle; identify perceived present and potential dangers to the vehicle, occupants, and other roadway users; and then automatically react to help avoid or mitigate crashes via various methods, including alerts, vehicle system adjustments, and active control of the vehicle motion subsystems (brakes, throttle, suspension, etc.). (Refer to SAE J3157.)

AUTOMATIC EMERGENCY BRAKING (AEB): Detects potential collisions with a vehicle ahead, provides forward collision warning, and automatically brakes to avoid a collision or lessen the severity of impact. Some systems also detect pedestrians or other objects. (Refer to SAE J3063.)

INFRARED (I.R.): Have a wavelength just higher than that of the red end of the visible light spectrum but less than that of microwaves. In this document, infrared refers to near-infrared radiation with a wavelength from about 800 nm to 1 mm. (Refer to SAE J3157.)

LiDAR: An active sensing technology that can measure the distance to, or other properties of, targets by illuminating the target with light and analyzing the backscattered light. (Refer to SAE J3157.)

4. SYMBOLS AND ABBREVIATIONS

AEB	Automatic Emergency Braking
IIHS	Insurance Institute for Highway Safety
IUPUI	Indiana University-Purdue University Indianapolis
LiDAR	Light Detection and Ranging
NHTSA	National Highway Traffic Safety Administration
Radar	Radio Detection and Ranging
RCS	Radar Cross Section
TASI	Transportation Autonomous Systems Institute
OSU	Ohio State University
CSRC	Collaborative Safety Research Center

5. METAL GUARDRAIL SURROGATE SPECIFICATIONS

The metal guardrail surrogate should provide sufficient details of the metal guardrail characteristics to satisfy the need of all state-of-the-art detection sensors. [Table 1](#) shows the metal guardrail characteristics that have a potential effect on the sensing outcome. They should be considered in the design specifications of metal guardrail surrogates.

Table 1 - Metal guardrail characteristics versus detection sensors

Sensor Type	Metal Guardrail Characteristics			
	Size and Shape	Viewing Angle	Radar Reflectivity	Infrared Reflectivity
Camera	X	X		
76-78 GHz Radar	X	X	X	
LiDAR/Active Infrared	X	X		X

The size and shape of metal guardrail surrogates affect all automotive sensors currently used for road departure mitigation. Metal guardrails have many shapes and sizes, as specified in various standards in different countries. The commonly seen metal guardrail has a W-beam, three-wave beam, steel cable, etc. The metal guardrail's commonly seen pole support includes I-beams, the round tube of different diameters, the square tube of different side lengths made of different materials. The variations are also in terms of coating, including galvanized steel (zinc-coated), rust-resistant steel, paint, and plastic coating. There are different thicknesses of the steel used for the W-beam, gauge 10 (2.75 mm) or gauge 12 (3.5 mm) [1]. The top of the horizontal rail is typically 737 mm $\pm$ 25 mm (29 inches $\pm$ 1 inch) above the ground in the United States. The distance between posts is 6 feet 3 inches (1.905 m). All variations, except the steel's thickness, affect either camera, LiDAR, or radar signatures of the metal guardrail.

The detection sensors are frequently exposed to metal guardrails from different horizontal and vertical angles during naturalistic driving. Assuming that the vehicle is always on the road and the roadside object is always on the roadside, the standard metal guardrail surrogate must represent the real metal guardrail from all 180-degree horizontal viewing angles and -90 to 90 degrees vertical viewing angles for the horizontal rail.

5.1 Size and Shape

This document uses the most commonly seen metal guardrail in the United States as an example for specifying the design specifications of the surrogate metal guardrail. Metal guardrail surrogates for other countries may be developed similarly.

The most common metal guardrails in the United States are galvanized steel W-beam with galvanized steel I-beam posts [2] ([Figure 1](#)). The shape of the W-beam is standardized in the U.S. The standard for guardrail with steel I-beam post is described in U.S. Customary Standard G4 W-Beam Guardrail Steel Posts [3]. The visible shape and size of the W-beam, I-beam, and the construction followed the U.S. DOT standard and described as in [Figure 2](#) [1, 3].

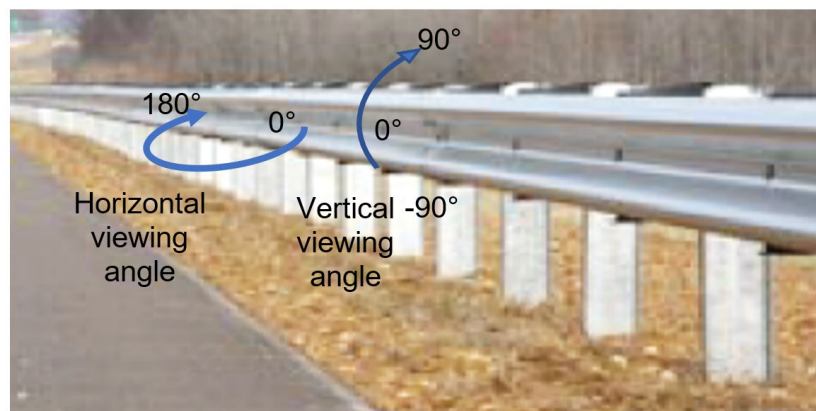


Figure 1 - Metal guardrail with W-beam and I-beam poles

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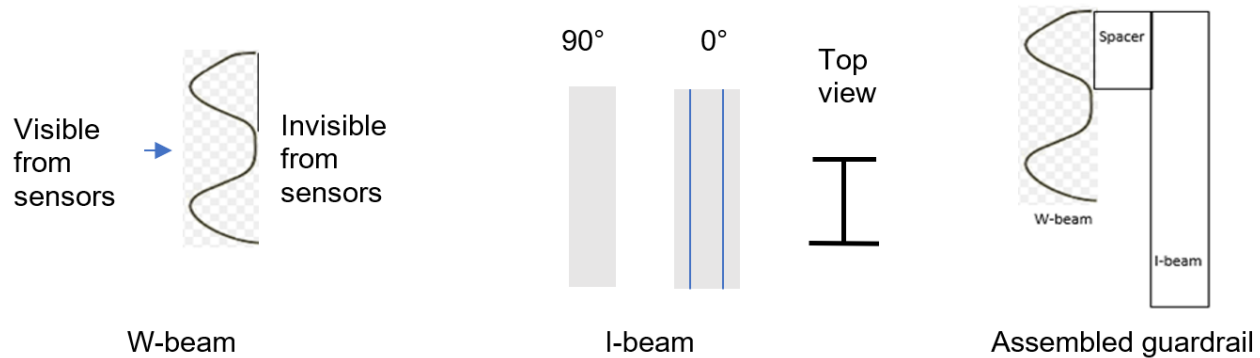


Figure 2 - W-beam and I-beam posts

5.2 Color

The goal of specifying the color of the metal guardrail surrogate is for testing the performance of the automotive cameras commonly used in active safety systems. The surface of the metal guardrail can be zinc galvanized, painted, or plastic coated. In North America, most metal guardrail is commonly made of galvanized steel. According to the study of 1478 metal guardrail images sampled all over the United States from Google street view [4], the representative color is zinc oxide grey with RGB range from (168, 168, 168) to (112, 113, 112) ([Table 2](#)).

Table 2 - The representative color range of the metal guardrail

Metal Guardrail	RGB Values	Range ($\pm 10\%$ brightness)	
Representative color	138, 139, 139	168, 168, 168	112, 113, 112

5.3 Infrared Reflection

The actual 3D-image mapping capability has made LiDAR a popular active safety sensor for intelligent vehicles. Modern automotive LiDAR can provide details about the target's speed, direction, and location (XYZ coordinates). The goal of specifying the infrared (I.R.) reflectance of the metal guardrail surrogate is to ensure the surrogate provides the same LiDAR reflectance as the real metal guardrail in various viewing distances and angles. The I.R. discussed here is near-I.R. (800 to 1600 nm) but not far-I.R. (5 to 1000 μm) used in temperature measurement. Up until now, most automotive LiDAR uses laser beams between 800 nm and 1100 nm. More recently, vendors are in the process of developing a new generation of LiDAR operating at wavelength 1550 nm. Since I.R. penetration depth is at the micrometers level, the I.R. reflectivity is contributed by the metal guardrail's surface only.

5.3.1 The Operating Principle of the LiDAR

The LiDAR emits laser pulse signals to a target and measures the amount of time each pulse takes to bounce back from the target [5]. Since the light speed is a constant, LiDAR can calculate the distance between itself and the target based on the light traveling time. The detectability of an object by a LiDAR depends on the reflected signal power from the object, i.e., the received power [6]. The reflected signal power is proportional to the I.R. reflectivity of the object's surface and inversely proportional to the square of the distance between the LiDAR and the object.

The LiDAR reflectivity of an object is a function of the wavelength of the laser emitted by the LiDAR. It is also a function of the surface texture of the object. When the surface is smooth like a mirror, all emitted light is reflected in one direction, and the laser reflection is defined as the specular reflection. When the surface is rough, the LiDAR emitted light is reflected in many directions, and the laser reflection is defined as the diffuse reflection (see [Figure 3](#)). For automotive LiDAR, the illumination angle and the measurement angle are the same. Therefore, the reflectivity of the surface of an object changes as the measurement angle changes. For a specular object surface, the reflected light is the strongest when the LiDAR is perpendicular to the surface and almost none when the LiDAR is not perpendicular to the surface. For a diffuse object surface, the reflected light's power is a function of the object's viewing angle. It should be noted that this is not the case for different surface materials and textures of objects.

5.3.2 Infrared Reflectance Measurement Instrument and Method

The methods and equipment for measuring specular reflectance and diffuse reflectance are very different, and the measurement of specular reflectance is quite complicated and costly. Since it is related to a small viewing angle range, specular reflectance measurement is not essential for this recommendation. Diffuse reflectance is seen in wider viewing angles of an object, and its measurement is relatively easy. Therefore, diffuse reflectance measurement is commonly used to describe the object's LiDAR property. The diffuse reflectivity has a value from 0 to 1. A value of 0 means no diffuse reflectivity (no light reflected, or the object surface absorbs all light). A value of 1 means light is evenly reflected in all directions.

For instance, both diffuse reflectance and specular reflectance are observed on the metal guardrail. Specular reflectance is attributed to the smoothness of the metal guardrail surface with respect to wavelengths. Since the illumination angle and the measurement angle of a LiDAR are the same, the specular reflection of a metal guardrail occurs when the LiDAR beam is perpendicular to the guardrail surface. Based on the I.R. measurements, the specular reflection of various galvanized steel is very influential when the illumination angle (same as the measurement angle for LiDAR) is 0 to 20 degrees; here, 0 degrees is defined when the light is perpendicular to the surface. From 20 to 90 degrees, the diffuse reflection dominates.

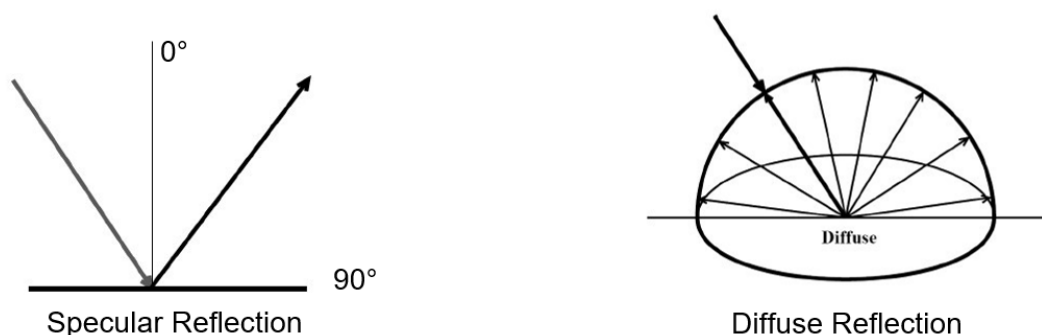


Figure 3 - Specular and diffuse reflection

A specific LiDAR uses only one specific wavelength, but automotive LiDARs on the market use many different wavelengths depending on the make and model. Hence, individual LiDAR is not suitable to be used for characterizing the reflectance of the metal guardrail. A spectrometer covering the I.R. 800 to 1600 nm wavelength range with a spectral resolution of 20 nm should be sufficient to measure the object's I.R. reflectance across multiple wavelength ranges [7]. The process for the measurement of I.R. reflectance of a target object is briefly described here. At first, the spectrometer measures reflected power, P_r , under an intended conditions (distance, angle, surface curvature, wavelength), from a reference flat white panel with a diffuse reflectance close to 1. Then the spectrometer measures reflected power, P_t , from the target object under the same conditions as the reference measurement. The diffuse reflectance of the object for the measurement angle is P_t/P_r .

Since the diffuse reflectance measurement calibration is used to measure the reflectance in all measurement angles, the specular reflective light influences the reflected light power when the measurement angles are more perpendicular to the object surface. Therefore, the reflectance values in the measurement angles in the 0 to 20 degree range are high and may even be greater than 1. Since we are interested in the real object and surrogate object's similarity, the value higher than 1 can still be used as a reference I.R. reflectance of the object.

5.3.3 The I.R. Specification of Metal Guardrail Surrogate

The U.S. roadside metal guardrails consist of W-shaped beams and I-shaped posts. The I-beam has flat surfaces, whereas the W-beam does not have a flat surface. The curvy surfaces of W-beams make their I.R. reflectance measurement difficult. Since both W-beam and I-beam are made of the same galvanized steel, it is sufficient to measure only the I-beams's I.R. reflectance.

Based on the measured I.R. reflectance of metal guardrails of different ages over the spectrum of 800 to 1600 nm wavelengths, it is found that the I.R. reflectance of the galvanized steel decreases as the measurement angle increases for the same wavelength (see [Figure 4](#)). The galvanized metal guardrail's age does not affect its reflectance [8].