

CONTRAST BETWEEN ROAD AND ROADSIDE MATERIALS FOR ROAD EDGE DETECTION IN VEHICLE ROAD DEPARTURE MITIGATION SYSTEMS

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ABSTRACT

Vehicle roadway departure crashes results in a large number of fatalities in the U.S. Road departure mitigation (RDM) systems rely on the road edge and road boundary identification. Cameras are widely used in RDMS for identifying road edges. The contrast between road and road boundary objects is one of the key image features used by the camera to detect road edges. This paper analyzes and compares the contrasts between various road surfaces and road edges.

INTRODUCTION

Road departure (RD) crashes are frequently severe and account for a large number of fatalities in the United States. According to the report from Federal Highway Administration (FHWA), an annual average of 19,233 fatalities resulted from roadway departure from 2015 to 2017, which is 52 percent of all the traffic fatalities in the United States [1].

A road departure crash is defined as “a non-intersection crash which occurs after a vehicle crosses a road edge line or a center line, or otherwise leaves the traveled way” [2]. To effectively prevent RD crashes, the Federal Highway Administration (FHWA) has developed several strategic approaches and plans, which focus on three objectives: 1) Keep Vehicles on Roadway, 2) Provide for Safe Recovery, and 3) Reduce Crash Severity [1]. While these countermeasures implemented by FHWA are all infrastructures related, the new generation vehicles equipped with road departure mitigation (RDM) systems have been developed and introduced into the market in recent years. Vehicle RDM systems rely on sensors to detect the road edge or roadside objects [3, 4]. Three key sensors are used to detect the road edges, including camera, radar, and LIDAR. For the low-profile roadside objects, including grass, curbs, and gravel, the cameras are widely used in RDM systems. In general, camera sensors use multiple features for object recognition. The contrast between road and road boundary objects is one of the key image features, which could significantly affect the detection of the road edges [5, 6].

To support the evaluation of the RDM systems and help to improve the performance of RDM systems, a set of roadside surrogate objects have been developed by the Transportation Active Safety Institute (TASI) at Indiana University-Purdue University Indianapolis (IUPUI) [7-9]. The requirements for these objects are that they should have the same characteristics of the real U.S. roadside objects from the viewpoint of automotive sensors. This paper analyzes and compares the contrasts between various road surfaces and the low-profile roadside objects, including green grass, yellow grass, curbs, and gravels.

Google street view is used to gather the samples of the road and roadside objects in the United States. 24,762 randomly sampled road locations with street view images were used in this study. The road surface and road edge types of all these 24, 762 locations were identified. Considering only the images in which the roads do not have

clear road edge marking, 2,295 samples with green grass, 927 samples with yellow grass, 3,965 samples with curbs, and 771 samples with gravel were examined.

The contrast is defined as a function of gray levels of the road surface (new asphalt, old asphalt, concrete, and others) and roadside object (gravel, green grass, yellow grass, curb). A larger absolute contrast number means a higher contrast. Negative contrast number means that the road is brighter than the roadside; positive contrast number means that roadside is brighter than the road. Histograms are used to describe the sample distribution with respect to the contrast for each combination of the road surface and roadside.

THE ROADSIDE OBJECTS DATASET

Google Street View is used to gather the road/roadside object images in the U.S. The whole processing is shown in Fig. 1. 824,957 road locations in the U.S. were randomly sampled (including Hawaii and Alaska). Since these locations have significantly biased distributions such as concentration in small roads in the large rural areas, a stratified sub-sampling was conducted with the balancing consideration of road levels, geographic locations, and population densities. As a result, 44,000 stratified locations were generated. In our research, the high-resolution satellite top-view images and street-view images of these 44,000 road locations were purchased. Since the top-view images cannot provide sufficient resolution to determine roadside objects and analyze the contrast between roads and roadside objects, the street-view images at these locations were searched. However, only 24,762 out of 44,000 locations have street-view images, which are used in this study [8, 9].

Unlike the lane departure warning (LDW) system that uses the road marking to detect the road or lane markings, RDM systems detect the road edges without road markings or with obscure road markings. Thus, only the locations without road marking or with unclear road marking were considered in this study. As a result, a total 7,958 out of 24,762 locations have the low-profile roadside objects and do not have road markings or have unclear road markings. Among them, 2,295 samples have green grass roadside, 927 samples have yellow grass roadside, 3,965 samples have curbs, and 771 samples have gravel roadside. It should be noted that high profile roadside objects such as metal guardrails, concrete dividers, and traffic barrels are not studied in this paper.

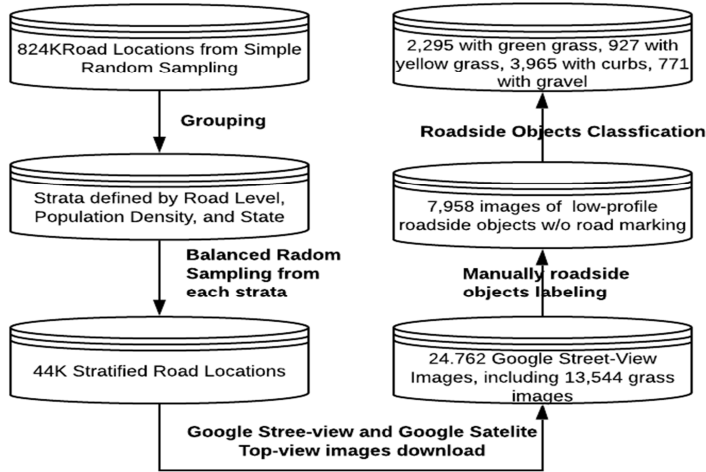


Fig. 1. The process of generating the data set of roadside objects.

THE DEFINITION OF CONTRAST

Contrast study is conducted in grayscale space. It is defined as a function of gray levels of the road surface (e.g., new asphalt, old asphalt, concrete, and others) and roadside object (e.g., gravel, green grass, yellow grass, curb). The calculation is shown in equation (1).

$$Contrast = \begin{cases} \frac{grayValue_{object}}{grayValue_{road}} - 1, & \text{if } \frac{grayValue_{object}}{grayValue_{road}} \geq 1 \\ -\frac{grayValue_{road}}{grayValue_{object}} + 1, & \text{if } \frac{grayValue_{object}}{grayValue_{road}} < 1 \end{cases} \quad (1)$$

This definition gives a continuous real number value. A larger absolute contrast number means higher contrast. If the contrast value is 0, it means that the brightness of the road boundary and road are the same (no contrast). If the contrast value is greater than 0, the roadside is brighter than the road. If the contrast value is less than 0, the road is brighter than the roadside.

To determine the contrast between the road and road boundary objects on an image, the representative samples on the road and roadside need to be gathered. A graphical user interface (GUI) was developed (shown in Fig. 2) to support manual marking on the road edges and to pick the representative sampling points on the image.

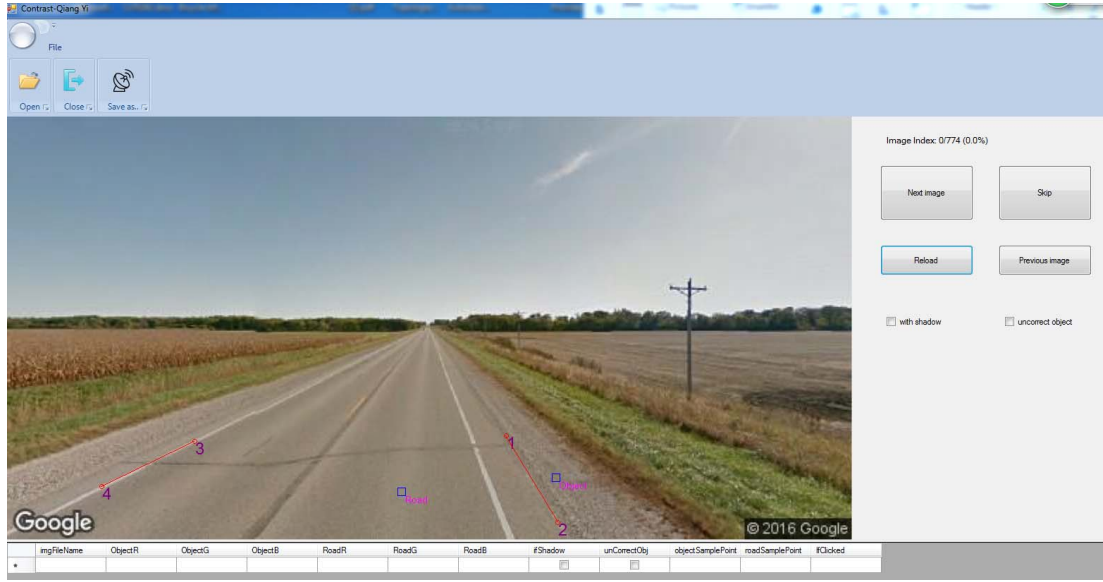


Fig. 2. The GUI for road edges marking and sample point selection.

THE RESULTS AND DISCUSSION

The contrast between roads and the road boundary with green grass

2,295 sample images of roadside green grass, which cover different road levels in the U.S. were used to obtain the contrast between the green grass and the road. Among these 2,295 sample images, 1,969 images have asphalt road, 98 images have a concrete road, and 228 have other types of road. Other types of the road include dirt, gravel, snow-covered road and wet road. It should be noted that the green grass and yellow grass was separately discussed because of their obvious visual differences. The definition of green and yellow grass could be found in [9].

Fig. 3 shows the overall distribution of contrasts of all road samples with the green grass road boundary. The horizontal axis is the contrast value; the vertical axis is the sample count. As shown in this Fig. 3, the contrast varies significantly, spreading from -5.13 to 1.23. The maximum distribution falls in the range of -0.3 to -0.2. Fig. 4 to Fig. 6 show the contrast distributions of the green grass boundary with different road types including asphalt, concrete, and others. The contrast distribution with asphalt road is similar to that of the overall roads. It spreads from -5.13 to 1.23. The range with -0.3 to -0.2 has the highest distribution. Different from that of the asphalt roads, contrasts between concrete roads and green grass roadside concentrate on the range of -0.65 to -0.25. They cover 62.2% of the concrete roads. The distribution of contrasts between green grass roadside with other types of roads including dirt,

gravel, snow-covered road and wet road shows a similar tendency with the overall distribution, but it is more concentrated. About 62.7% of the other types of road fall in the range of -0.6 to -0.2.

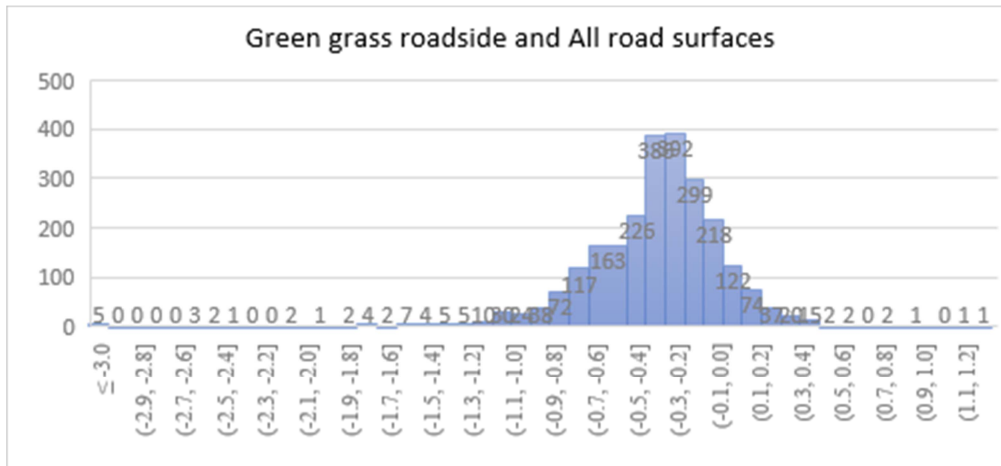


Fig. 3. The distribution of contrasts between all roads and green grass road boundaries.

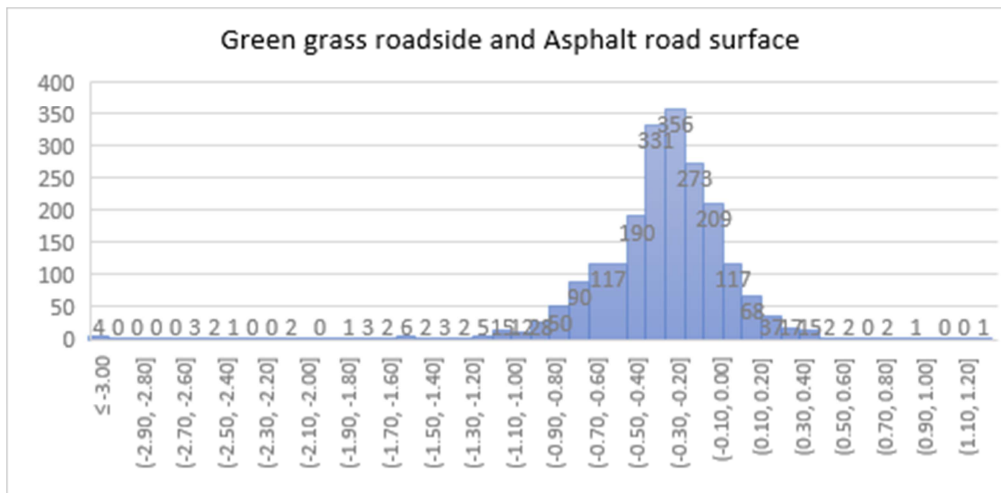


Fig. 4. The distribution of contrast between asphalt roads and green grass road boundaries.

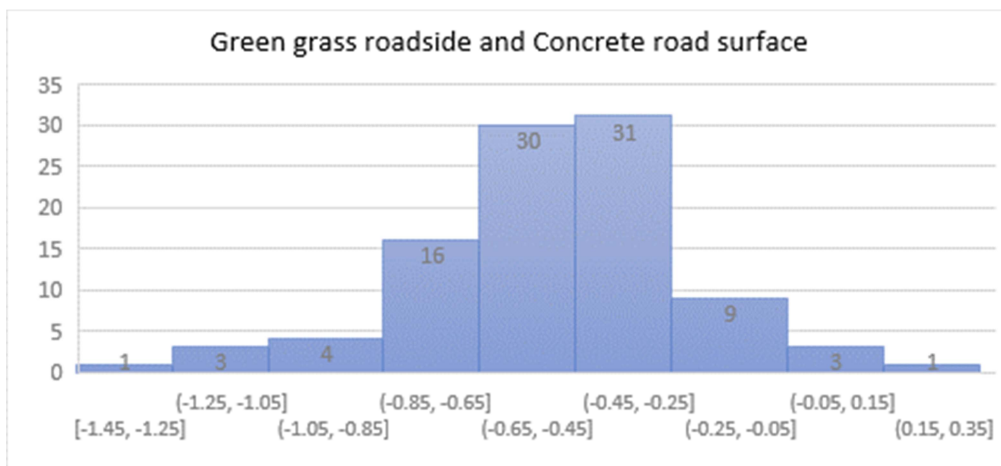


Fig. 5. The distribution of contrasts between concrete roads and green grass road boundaries.

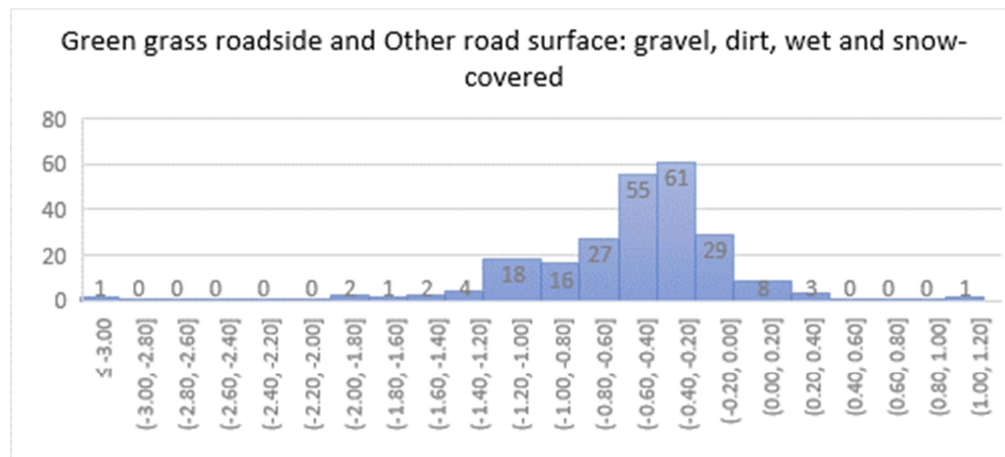


Fig. 6. The distribution of contrasts between other road types (including dirt, gravel and wet) and green grass road boundaries.

The contrast between all roads and the road boundary with yellow grass

927 sample images with yellow grass roadside were used to obtain their contrast. Among them, 827 images are with asphalt road, 14 images are with concrete road, and 86 with other types of road, including dirt, gravel, and wet road.

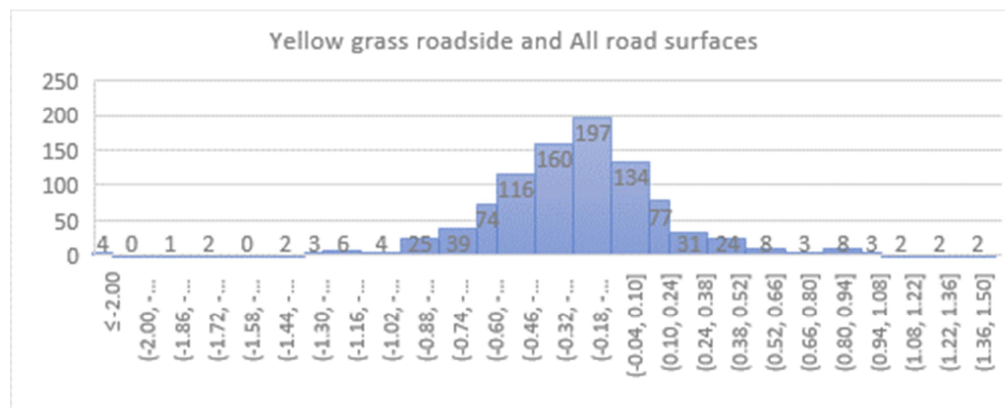


Fig. 7. The distribution of contrasts between all roads and yellow grass road boundaries.

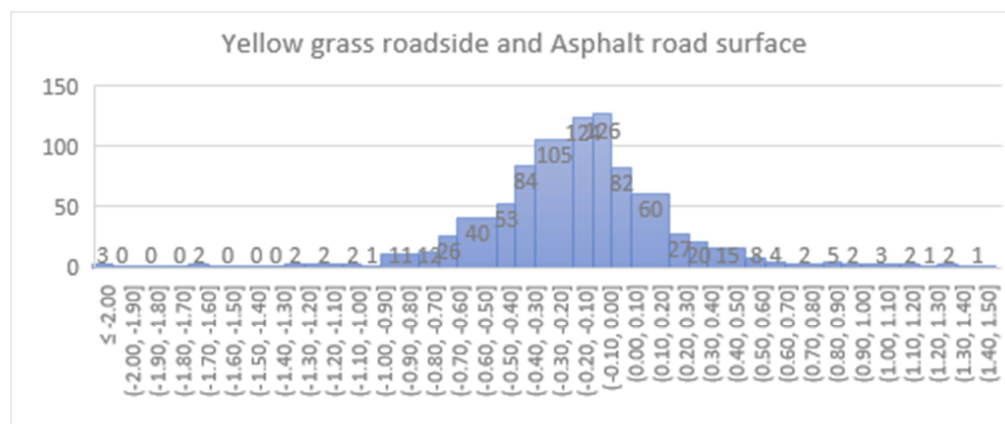


Fig. 8. The distribution of contrasts between asphalt roads and yellow grass road boundaries.



Fig. 9. The distribution of contrasts between concrete roads and yellow grass road boundaries.

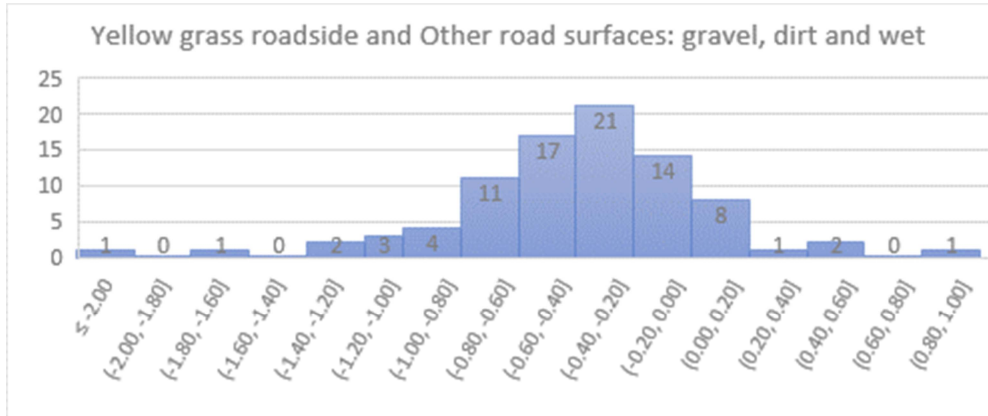
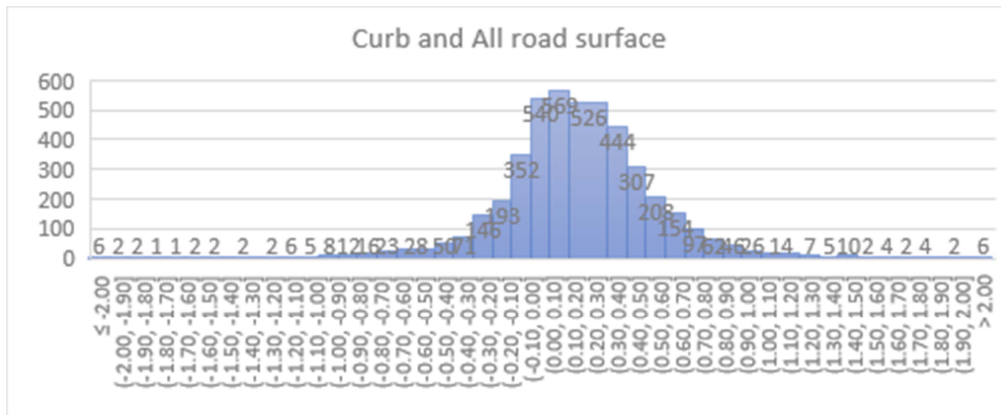


Fig. 10. The distribution of contrasts between other road types and yellow grass road boundaries.

The overall contrast distribution is shown in Fig. 7. It is similar to green grass, but the range is much narrower and more concentrated. The range varies from -2.27 to 1.47. The maximum distribution falls in the range of -0.18 to -0.04. Fig. 8 to Fig. 10 show the contrast distribution of different road types with yellow grass roadside. For the asphalt, the range -0.3 to 0 covers 42.9% of the asphalt roads. For the concrete road, only 14 samples are found. The contrast varies from -0.85 to -0.04. For other types of road, the highest frequency is in the range of -0.4 to -0.2.

The contrast between roads and curbs

Curb is the most common road edge in the U.S. without considering road edge marking. 3,965 images were used to obtain the contrast between the roads and curb. Among them, 3,673 images have asphalt roads, 248 images have concrete roads, and 44 images have other types of roads (including dirt, gravel, and wet road). Fig. 11 shows the distribution of contrast in all 3,965 samples. The range spreads from -3.81 to 2.66. The highest portion is in the range of 0.1 to 0.2. The asphalt road has the same distribution with the maximum distribution in the range of 0.1 to 0.2 (shown in Fig. 12). The contrast between curbs and concrete roads is low, and the highest portion goes to 0 to 0.1 (shown in Fig. 13). For other road types, the range of -0.1 to 0.3 covers 52.3 % of samples (see Fig. 14).



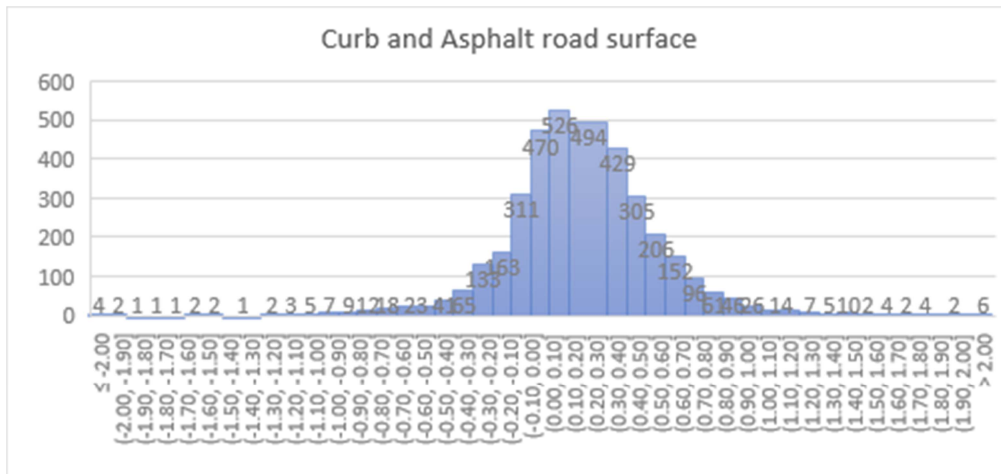


Fig. 12. The distribution of contrasts between asphalt roads and curb road boundaries.

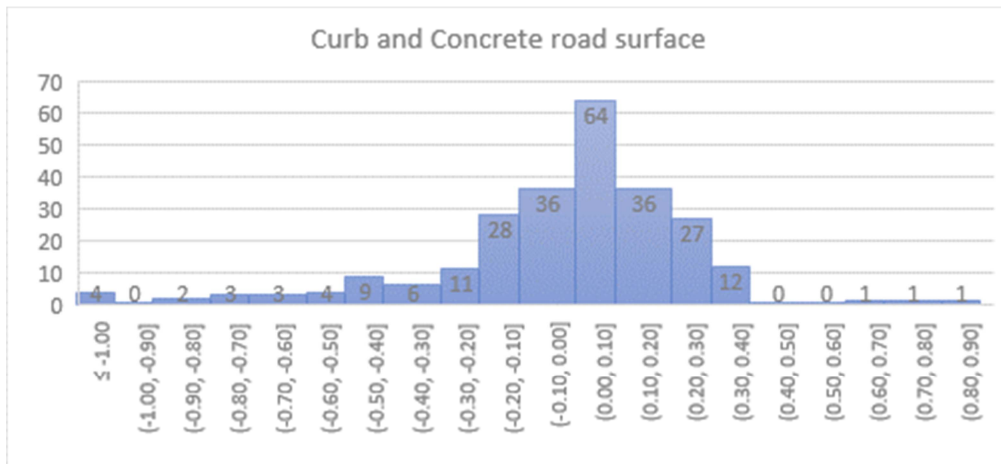


Fig. 13. The distribution of contrasts between concrete roads and curb road boundaries.

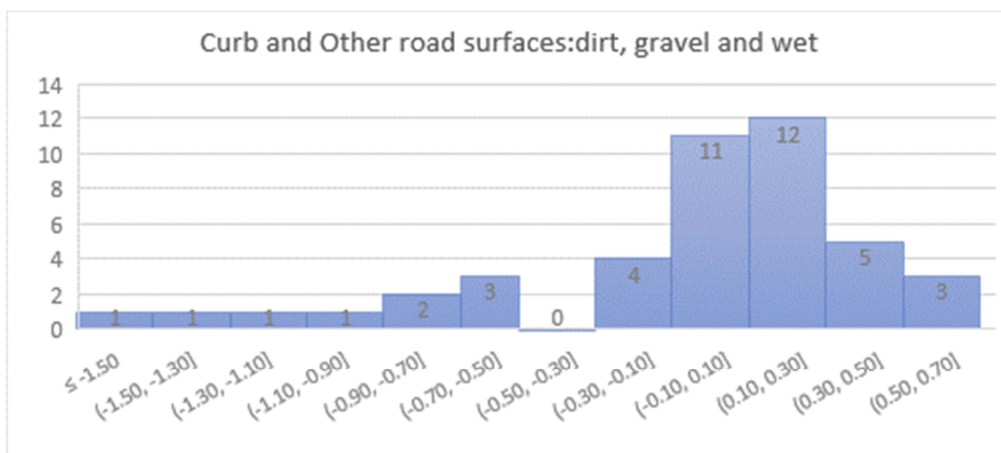


Fig. 14. The distribution of contrasts between other road types and curb road boundaries.

The contrast between the road and the gravel road boundary

771 sampled images with gravel road boundary were used to obtain the contrast. Among them, 698 images have asphalt road, 60 images have concrete roads, and 13 have other types of roads (including dirt, gravel, and wet road). Fig. 15 shows the overall contrast distribution. Comparing with other road boundaries, the contrast between all roads and gravel roadside is relatively low. The range varies from -1.73 to 2.02. The maximum distribution is in the range of -0.1 to 0. Fig. 16 to Fig. 18 show the contrast distribution of curb with asphalt, concrete, and other road types, respectively. The highest distributions are 0.1-0.2, -0.13-0.07 and 0.27-0.23, respectively.

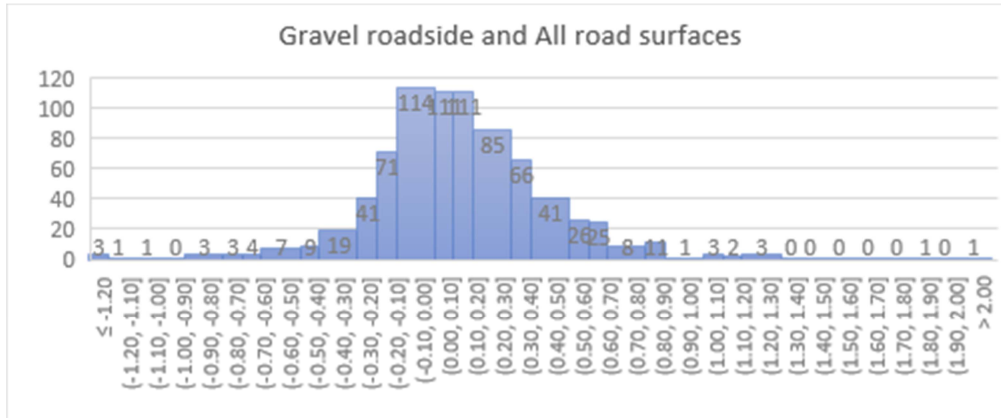


Fig. 15. The overall distribution of contrasts between roads and gravel road boundaries.

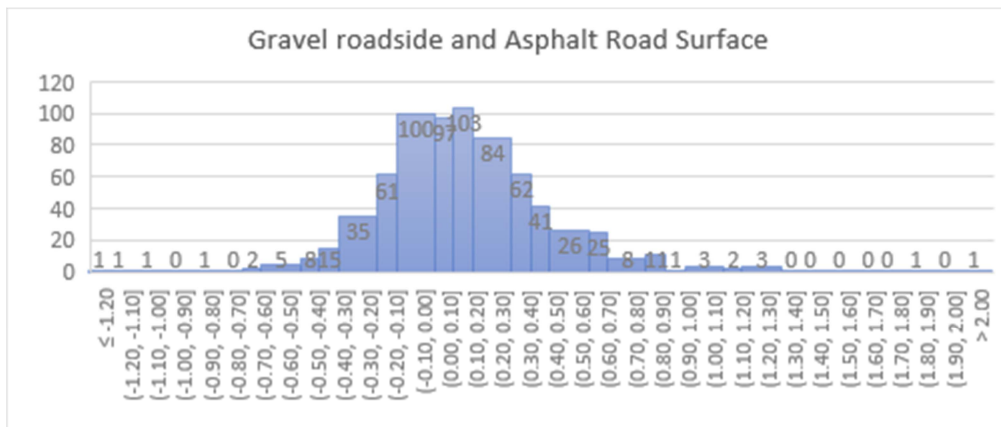


Fig. 16. The distribution of contrasts between asphalt roads and gravel road boundaries.

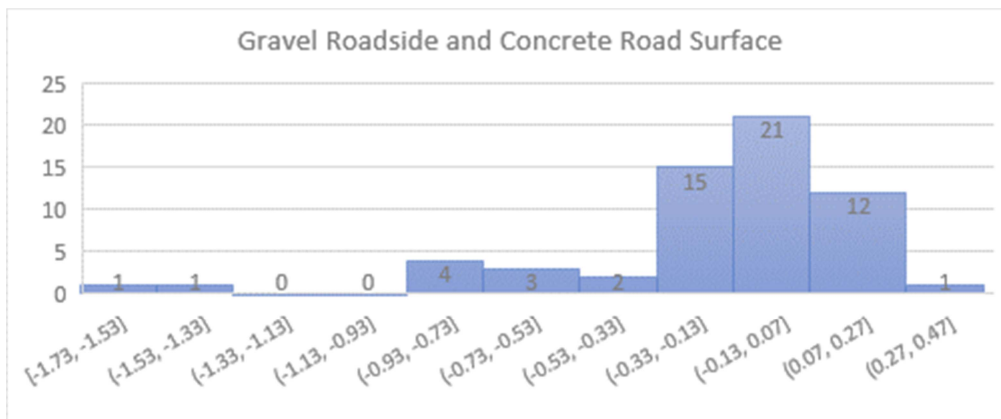


Fig. 17. The distribution of contrasts between concrete roads and gravel road boundaries.

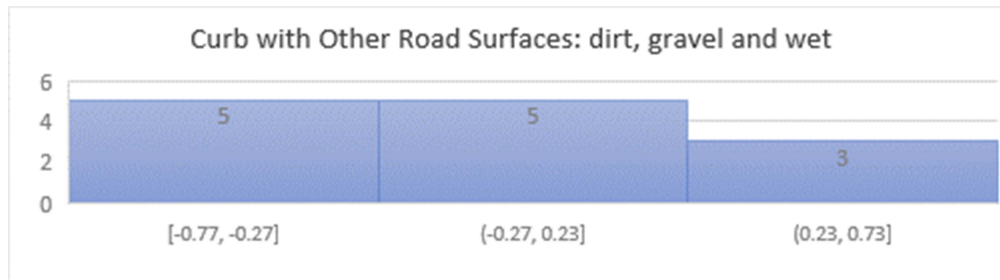


Fig. 18. The distribution of contrasts between other road types and gravel road boundaries.

CONCLUSIONS

This paper provides a contrast definition for analyzing the contrast between various road surfaces and the commonly seen low-profile roadside objects. Contrast values were surveyed based on randomly sampled 7,958 Google street-view images. The range and distribution pattern of contrast between the combination of the road surfaces and roadside were obtained and discussed.

The contrast of asphalt roads and green grass roadsides spreads from -5.13 to 1.23, but most frequently seen contrast is between -0.3 and -0.2. The contrast of concrete roads and green grass roadside spread from -0.45 to 0.15 with 62.2% concentrates between -0.65 and -0.25. The contrast between the concrete road and the curb is from -1 to 0.4 with the majority between -0.2 and 0.2, that means small or no contrast. The most frequently seen contrast of old asphalt road and yellow grass is in the range of -0.1 to 0. Table 1 is a summary of contrast range between different road surfaces and roadside object types, which covers the highest percentage of the samples in descending order. A positive value means that the roadside is brighter than the road. A negative value means that the road is brighter than the roadside.

Table 1.
Summary of the contrasts between road surfaces and roadsides

	Asphalt road	Concrete road	Other roads	Note
Green grass	$[-0.3, -0.2]$	$[-0.45, -0.25]$	$[-0.4, -0.2]$	Road is brighter
Yellow grass	$[-0.1, 0]$	$[-0.55, -0.25]$	$[-0.4, -0.2]$	Road is brighter
Gravel	$[0.1, 0.2]$	$[-0.13, 0.07]$	$[-0.77, 0.27]$	Similar to road
Curb	$[0.1, 0.2]$	$[0, 0.1]$	$[0.1, 0.3]$	Curb is brighter

ACKNOWLEDGMENT

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