Detection of The Wet Area of The Road Surface Based on a Saturated Reflection

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Abstract This paper proposes a method to detect the wet area of the road surface by using a single camera. The main idea of this method is that the intensity trend on the same road surface point can be tracked by converting the input image to a Top-View image using a planar projection matrix, homography. The method is mainly composed by 2 algorithms. The first algorithm estimates the velocity of the vehicle. The second algorithm detects the wet area of the road surface by checking the intensity transition of the reflection. Thus, polarization lens is unnecessary. A single camera and its calibration information is only required. Experiments are done with both synthesized and real images and good results are obtained.

Key words Homography, ITS, Reflectance

1. Introduction

Recently, there are many researchers who work in the area of Intelligent Transport System (ITS). Specially, there is a great interest in the assist system for a safety drive which is mounted on the vehicle. The ITS can be divided in to 2 categories, whether the system it self is mounted on the vehicle, or not. The system mounted on the vehicle will process the information collected from the outside of the vehicle, and estimate or detect useful information for the safety drive.

In this paper, we propose a method which detects the wet area of the road surface by using the information obtained from a single camera, fixed on a vehicle. The wet detection is based on the statistics of the reflection intensity.

A wet road is danger compared to a dry road since the surface of the road is slippery. The Antilock Brake System (ABS) will control the brake of the vehicle only if the tires start slipping. ABS do not know whether the road is wet or not. We believe that the vehicle will much more safety by combining the road surface information and the ABS. Thus the final goal of the proposed method is to detect the wet area on the road surface for a safety drive.

In previous works, many researchers used a polarization camera [1] or a camera fixed above the road [1], [2]. Compared to them, the proposed method uses a normal camera fixed on the vehicle. This is a big difference against the previous methods. The polarization lens is unnecessary, and camera can move as long as it is fixed on a vehicle.

The method which estimates the wet area proposed in this paper is composed by 2 steps. The main idea of the proposed method is using the relation between the 2 planes, the ground plane and the image plane.

In the fist step, the system estimates the velocity of the vehicle as described in sec. 3.. In the second step, the system distinguish the areas by the statistics information of the intensity. The second step is described in sec. 4.

The rest of this paper is organized as follows. Section 2. describes the detail of the planar projection, homography. Section 5. expresses the result obtained by the proposed method. Finally, Sect. 6. concludes this paper.

2. Planar Projection (Homography)

Homography is a geometric relation between the 2 planes which corresponds of the coordinates uniquely. It is expressed by a matrix of 3 by 3 as shown in Eq.(1).

$$s\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} \cong \mathbf{H}\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix}\begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} \quad (1)$$

In the Eq.(1), $\mathbf{H}$ denotes the homography, $(x,\ y,\ 1)^\top$ denotes the original coordinates, $(x',\ y',\ 1)^\top$ denotes the converted coordinates and s denote the scale factor. Homography can be obtained from the geometric relation (ex. distance, angle) of the 2 planes. The 2 planes in the proposed method are the ground plane and the image plane. By using the homography, an image can be converted to an image from another direction.

Fig. 1 shows the outline of the correspondence between

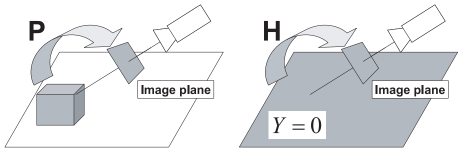
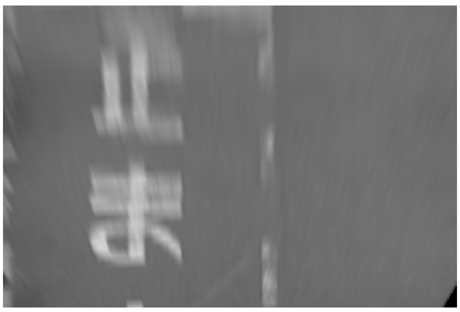


Fig. 1 The image of the usual camera and the homography

the 2 planes. The coordinate of the image plane can not be corresponded to a unique 3 dimension coordinate, but can be corresponded to a coordinate on the ground plane by using the homography. This means that input image can be converted to a Top-View image as shown in fig. 2.

(a) Example of the original input image



(b) Example of the Top-View image

Fig. 2 Example of the Top-View image and the input image

Fig. 2 shows the example of the Top-View image and the input image. The area expressed by the white line is converted to the Top-View image based on the calculated homography. This method was used by many researchers [3], [4].

3. Estimation of The Velocity

This section will describe the outline of the proposed method. Proposed method requires a single camera fixed on the vehicle. Figure 3 shows the image of the system. The height and the angle of the camera against the ground level are known. The camera's axis is fixed to the direction of the vehicle and showing the ground in front of the vehicle.

The basic idea of the proposed method is composed by 2 steps. The first step is to find the correspondence area on the road between the 2 consecutive frames. This step is equal to estimate the vehicle's velocity v shown in fig. 3. The second step estimate whether the area is wet or not by the transition of the intensity. This is done by comparing the intensity of the reflection $I_1 - I_3$ in fig. 3.

The proposed method only handles the situation during the daytime and the road with a some kind of texture drawn on. The first step of the method is described in this section, and the second step is described in section 4..

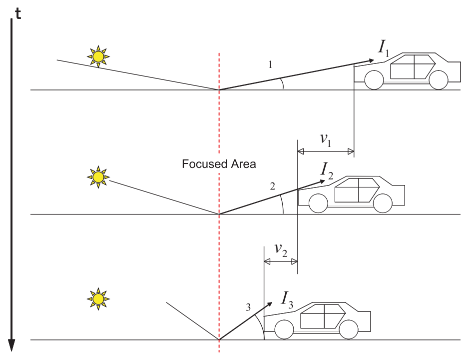


Fig. 3 The angle against the focused area on the ground

Since the relation between the camera and the ground is known, geometric position of the image plane and the ground plane can be expressed by planar projection as shown in Section 2. Thus, the input image can be converted to a Top-View image.

To find the positions of the same focused are in 2 consecutive frames, the velocity of the vehicle is required due to the movement of the vehicle. Since the proposed method is trying to estimate every information from the camera, the method will estimate the vehicle's velocity from the captured images instead of using it's speed sensor.

The proposed method estimates the velocity parameter of the camera by the iteration of the assumption and the evaluation. If the parameter fits to the input images, its evaluated parameter becomes high. Proposed method estimates the parameters by iteration of the evaluation of each candidate parameters. In another word, this process is equal to the registration of the 2 consecutive frames of the input images.

This convert decreases the computation time. The original velocity includes 6 parameters to estimate, 3 degrees for the translation and 3 degrees for the rotation. By converting the input image to the Top-View image, another constraint can be introduced to registrate the images. This reduces the number of the parameter from 6 to 2, the angle of the direction and the length which vehicle moved in 1 frame, in another word, the vehicle's speed.

In the beginning, an assumption is made that in front of the vehicle, there is a region that no moving object is included. If the 2 velocity parameters, v and θ are correct, the 2 Top-View images must become identical. The similarity of the 2 Top-View images corresponds to the relevance of the 2 velocity parameters. For each Top-View images, the similarity is calculated. For the similarity evaluation, SAD value is used in the proposed method.

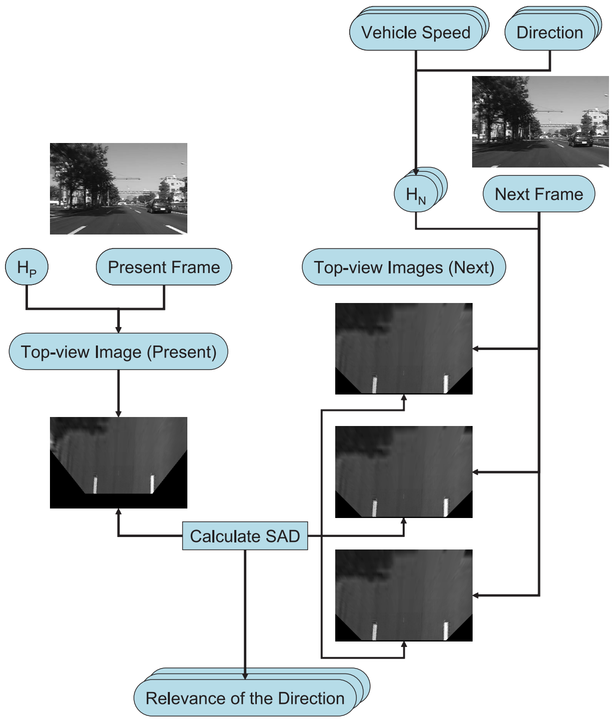


Fig. 4 The outline of the process to estimate the velocity

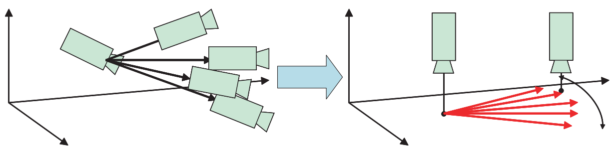


Fig. 5 Converting the image to the Top-View image

The biggest feature of the proposed method is that it doesn't require any explicit marker in the image [5], [6], [7]. In the division of ITS, many systems assume that there is a lane marker drawn on the road. This means that many methods can not be applied in the situation where the lane marker is not seen, such as snow road. Since the proposed method do not require lane marker on the road, it is robust to the marker on the road than the other methods.

4. Wet Area of The Road Surface

By focusing on a certain area on the road, the angle against the ground changes since the vehicle moves. To focus on a smae area , the volocity information estimated in sec. 3. are used. If the focused area is wet, the surface of the focused area makes a specular reflection. In another word, the intensity of the reflection of the surface changes very much. If the ground is not wet, the surface's reflection doesn't change according to the lambertian model.

Now, we handle the situation of the sunny day. Thus, the reflection becomes very strong, that the saturation occurs in the image as shown in Fig. 6. This saturated reflection occurs only when the light source comes directly into the camera. If the camera's position changes and the angle of reflection of the lights changes, the reflection becomes very darks. Thus, by tracing the intensity of a certain focused area, the road can be distinguished whether it is wet or dry.

We introduce 2 types of threshold to distinguish the situation. The threshold of the variance th_{var} and the threshold of the average intensity th_{ave}. If the road makes a saturated reflection, both average and the variance of the intensity of the road surface change. Thus, if both value get higher than the thresholds, the area is distinguished as wet.

Fig. 6 The surface of the wet road and the dry road

The focused area in the input image moves in both x and y axis since the camera is not fixed perpendicular against the ground. This causes the trace of the focused area in both x and y axis, as shown in Fig.7. By converting the input image to the Top-View image, the trace of the focused area is needed only in the y axis. This makes the process of the trace of the focused area more easily.

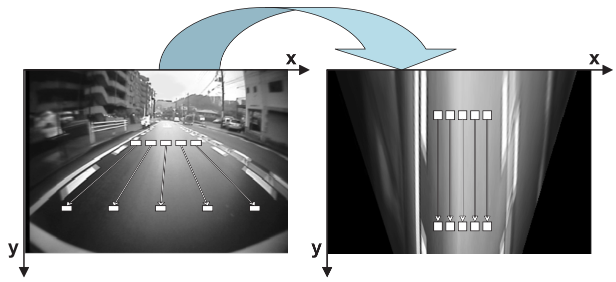


Fig. 7 The trajectory of the same area in the input and the Top-View image

To distinguish whether the area is wet or dry, the detection of the change of the intensity is required. First, the average intensity of the pixels included in the focused area is calculated and then the variance of the intensity among the time domain is calculated.

Fig. 8 shows the intensity of the surface of the wet road. Each row expresses the same focused area and each column expresses the time domain instead of the position. In the circled area, the reflection of the road surface has changed strongly. This is the specular reflection caused by the wet road surface.

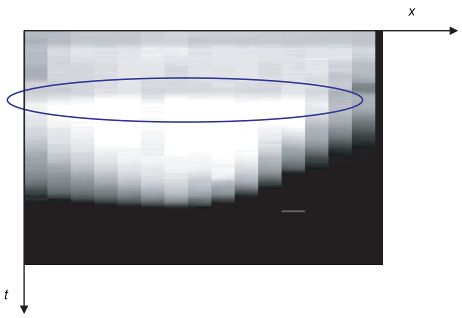


Fig. 8 An example of the change of the intensity on the wet road.

5. Experiments

To examine the proposed method, the experiments are done. The proposed method has been applied to both synthesized and real images. The experiment with synthesized images in sec. 5.1 checks whether the statistics have enough information or not to detect the wet area. The experiments with real images in sec. 5.2, 5.3 show that the proposed method can distinguish the wet and the dry road in real scene.

In the experiments, the road surface has been divided in to small squares. The square area estimated as a dry area is surrounded by a white line, and the area estimated as a wet area is surrounded by black line.

5.1 Experiments on Synthesized Images

The proposed method has been applied to a synthesized images to show that it can detect the wet area of the road. The image sequence was synthesized by POV-Ray 3.6. As shown in Fig. 9, there are some water pools on the road surface. The camera moves straight forward above the road. The gray circle in the image is the wet area.

The result is shown in Fig.10. As the Fig.10 shows, the circle wet area is detected correctly.

This means that if the wet road surface makes a specular reflection, the proposed method can detect the wet area on the road.

5.2 Experiments on Dry Real Images

In this section, the proposed method has been applied to a road images which are dry. The example of the input images are shown in Fig. 11, and the results are shown in Fig. 12. Each threhold was $th_{var} = 200$ and $th_{ave} = 150$. The intensities of the entire frame are used to calculate the statistics.

An example of transition of the intensity is shown in Fig.

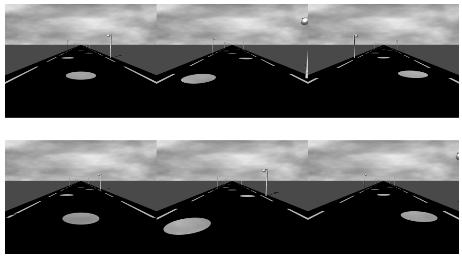


Fig. 9 The examples of the synthesized input images

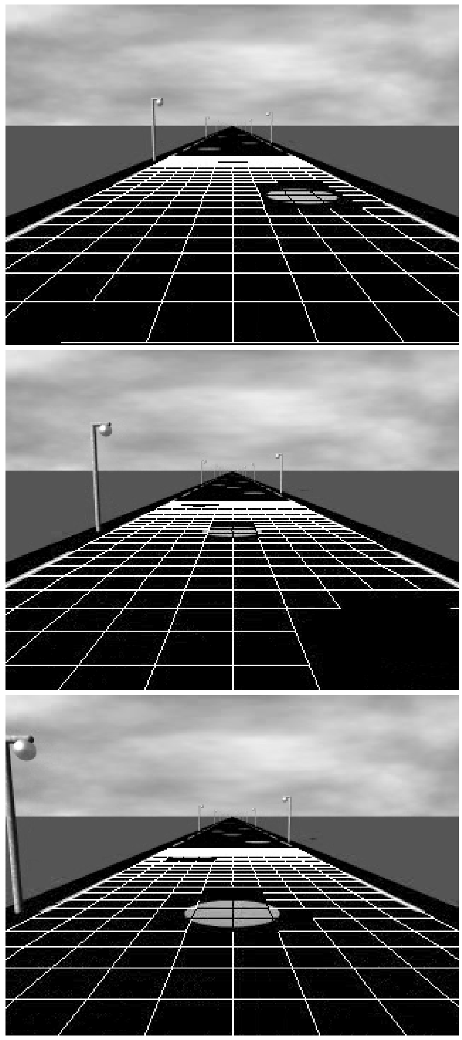


Fig. 10 The detected wet area of the road surface

13 and the transition of the variance and the average of the intensity is shown in Fig. 14. The data group "Side" and "Center" correspond to the intensity transition of the end of the right side and the center of the search area which is drown in Fig. 12. The line drawn in Fig. 14 denotes th_{var}.

As shown in Fig. 12, the area on the road surface are surrounded by white line. The variance and the average of the intensity are small during the sequence as shown in Fig. 14. This means that the proposed method estimates the dry area correctly.

5.3 Experiments on Wet Real Images

In this section, the proposed method has been applied to a

Fig. 11 Example of the real images of the dry roads

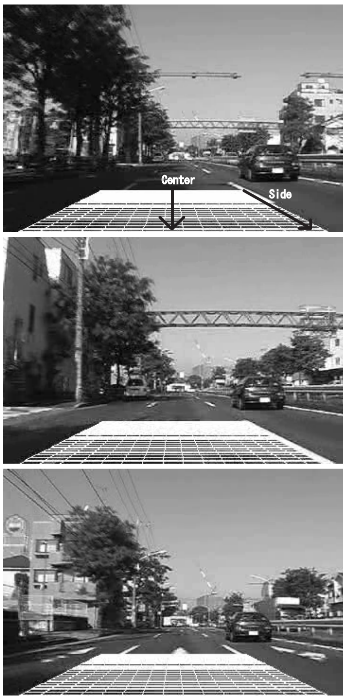


Fig. 12 Detected dry area on the road surface

road with a wet surface. The example of the input images are shown in Fig. 15, and the results are shown in Fig. 16. Each threhold was $th_{var} = 200$ and $th_{ave} = 150$. The intensities of the entire frame are used to calculate the statistics.

An example of the transition of the intensity is shown in Fig. 17 and the transition of the variance and the average of the intensity is shown in Fig. 18. The line drawn in Fig. 18 denotes th_{var}.

As shown in Fig. 16, the proposed method estimates the

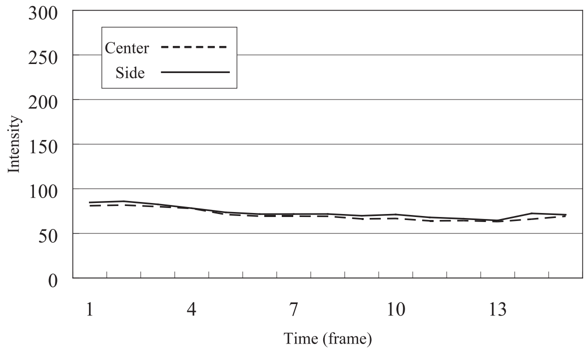


Fig. 13 Transition of the intensity of the reflection on the dry road

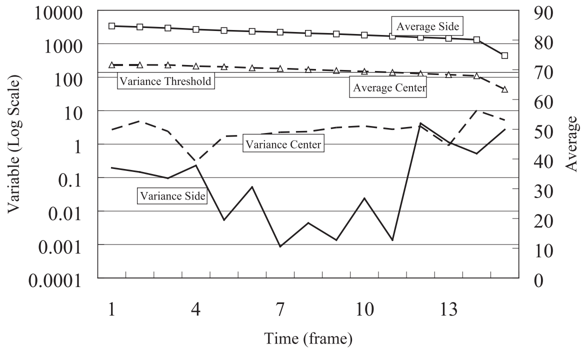


Fig. 14 Transition of the variance and the average of the intensity on the dry road

wet area correctly. In some situation, the road are estimated as dry. These situation occurs when the reflection of the road surface is not enough.

As the Fig. 17 shows, the intensity of the reflection area is saturated in the beginning.

6. Conclusion

In this paper, a method to detect the wet area of the road surface by using a single camera fixed on the vehicle has been proposed.

The main idea of the proposed method is to convert the input image to a Top-View image according to homography. By using the Top-View iamges,

Any explicit marker is unnecessary for the method. This is the difference against the other systems which has a camera mounted on the vehicle and has an interest on the road surface. Also, the proposed method requires only the calibratoin information. A special lens, nor marker is required.

Sinse the proposed method is using the saturated reflection for the detection of the wet area, the situation that proposed method can apply is limited. Also, the experiments requires wet road and sunny day. Thus, we do not have much input images. Furthur analysis of the reflection and experiments

Fig. 15 Example of the real images of the wet roads

Fig. 16 Detected wet area on the road surface

are required.

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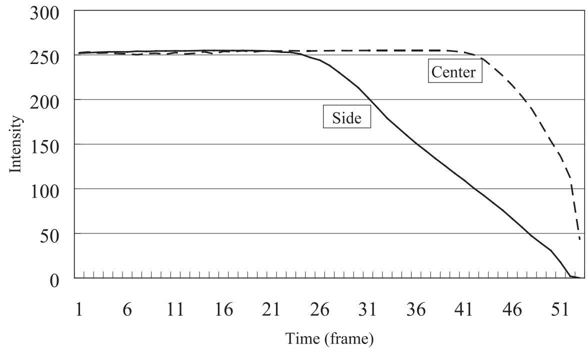

Fig. 17 Transition of the intensity of the reflection on the wet road

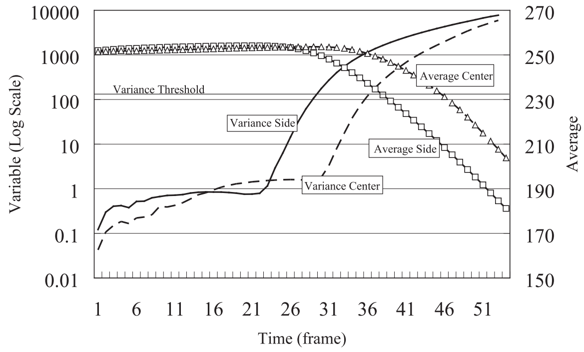

Fig. 18 Transition of the variance and the average of the intensity on the wet road

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