Panoramic-View- and Epipolar-Plane- Image Understandings for Street-Parking Vehicle Detection

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Street-parking vehicles cause many problems in urban traffic situation: blinds area, traffic congestions, and so on. Detection method of street-parking vehicles are proposed. The proposed method is based on epipolar-plane image (EPI) analysis. First, our proposed method detects edges in EPIs by applying Hough transformation. By computing depth variation from slope of detected edges, street-parking vehicles can be detected. In our experiments, detection rate reached 76.9%.

Keyword: Object Detection, Image Understanding, Motion Stereo, Panoramic-View Image, Epipolar-Plane Image, Street-Parking Vehicle, High-Frame-Rate Camera

1 INTRODUCTION

In crowded urban areas, *street-parking vehicles* occupy a certain area of the streets at any time and cause traffic problems, such as impediment to the traffic flow and blind spots. In Japan, 1,800,000 parking tickets are issued annually. Among them, 480,000 parking tickets are issued in Tokyo alone. Illegal parking is a common problem in metropolises as indicated by the number of tickets issued annually, e.g., 10,000,000 in New York, 4,000,000 in London, and 2,800,000 in Seou [1].

In the United States and Europe, both police and local governments clamp down on illegal parking. In case of the local government, the criminal status of illegal parking is reduced or removed. In Japan as well as England, there is a plan to entrust the control of illegal parking to the private sector before long [2]. Nevertheless, illegal parking is not decriminalized.

Information about street-parking vehicles is useful for re-planning roads and traffic system. In Japan, street-parking vehicles have to be manually counted by investigators in measuring vehicles during traffic-condition survey. Manual counting faces problems, such as human error and high cost.

Feasible street-parking-vehicle counting system in term of accuracy and cost is desired for *privatization* and effective *traffic census*. We previously proposed the detection method by a scanning laser-range finder (LRF) [3]. However, occlusion such as from a vehicle going past the measurement vehicle leads to incorrect detection.

We proposed also an alternative detection method [4], based on an epipolar-plane image (EPI) analysis, which are easily obtained by a line-scan camera. However, the method is applicable during daytime and it needs much processing time.

Sakuma et al. [5] proposed the counting method by detecting wheels. The method creates panoramic images and extracts vehicle's wheels by morphological processing to those panoramic images. However, it is applicable only during daytime and its cost is high.

This paper introduces how to derive panoramic-view- and epipolar-plane- images (PVI and EPI) from spatio-temporal volume image. Next, this paper describes also a detection method based on an epipolar-plane image analysis [6]. EPI analysis, firstly developed by Bolles [7], is a technique for building a three-dimensional description of a static scene from a dense sequence of images. EPI analysis is used to calculate the *features* depth from the slope of *feature paths* in EPIs. Height-effect of epipolar planes will be discussed.

Experimental results will be described. In experiments, PVI and EPI are easily obtained by operating double line-scan cameras simultaneously.

2 PANORAMIC STREET IMAGE

2.1 Spatio-Temporal Volume

Two important cases in object detection are the detection of moving objects from a stationary camera and vice versa. In the first case, image subtraction and background subtraction are often used. In the latter case, *motion stereo* is often used for extracting

3-D information from 2-D images of stationary objects.

This paper focuses on detection of stationary objects by a camera with *lateral motion*. Lateral motion is illustrated in Fig. 1. While the camera moves laterally, a target P is projected to points P_1, P_2 and P_3 on the camera's image plane at time T_1, T_2 and T_3, respectively. The plane on which there are the target P and arbitrary two camera optical centers, is called an *epipolar plane*. The epipolar plane intersects two corresponding image planes along an *epipolar line*. Epipolar lines on the image plane for a lateral motion are collinear and parallel to the camera optical center's trajectory.

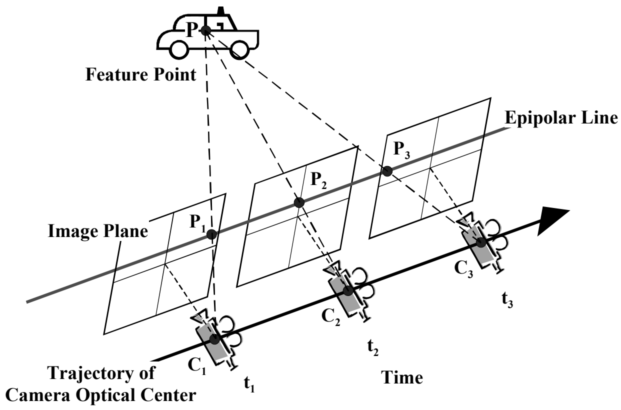
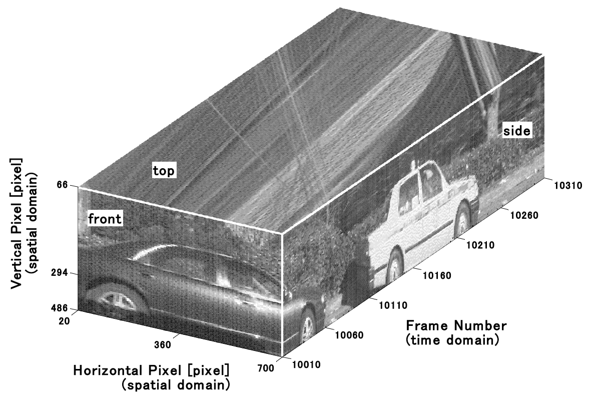


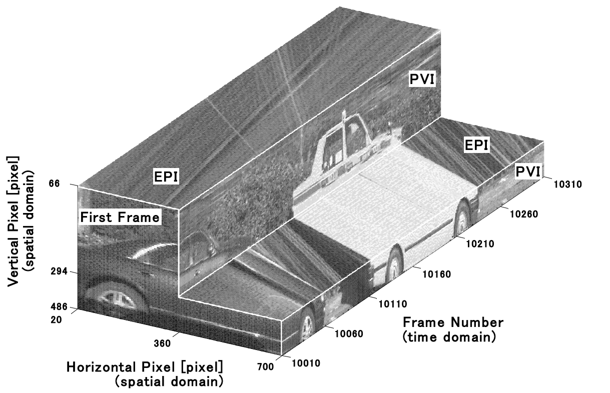
Fig. 1 Lateral motion of camera. A camera optical center is located at points C_1, C_2 and C_3, and a feature point P is projected to points P_1, P_2 and P_3 in the image plane, at time, T_1, T_2 and T_3, respectively.

Our algorithm considers a 3-D spatio-temporal volume, which is a *multiframe array* generated by concatenating multiple image frames along the time domain. The multiframe array is a 3-D volume in a spatio-temporal domain. The camera moves laterally, the background also sweeps across multiple image frames. In this case, two important 2-D images can be generated from a 3-D spatio-temporal volume.

The two images are derived by slicing a 3-D spatio-temporal volume: (1) an epipolar-plane image (EPI) from horizontal slicing, and (2) a panoramic-view image (PVI) from vertical slicing. The result of the slicing process is shown in Fig. 2. The front plane of the 3-D spatio-temporal volume is the first frame. Its side plane is a panoramic-view image. Its top plane is an epipolar-plane image. A panoramic-view image and an epipolar-plane image are created by slicing the spatio-temporal volume, vertically and horizontally, respectively.



(a)



(b)

Fig. 2 Spatio-temporal volume representation: (a) Spatio-temporal volume generated by concatenating multiple images along the time domain. The first frame is the front plane. Panoramic-view image is the side plane. Epipolar-plane image is the top plane. (b) Panoramic-view image and epipolar-plane image are created by slicing the spatio-temporal volume, vertically and horizontally, respectively.

2.2 PVIs and EPIs

We mount a camera on a moving vehicle and it captures line images at a constant frequency, orthogonal to the moving direction. PVI scheme is an *orthogonal-perspective projection* of scenes; orthogonal toward the camera path and perspective along the vertical lines.

The further the object, the lower the object is in PVIs. Object widths in PVIs are proportional to their real widths facing the street. In PVIs, the further objects are extended horizontally. Consequently, the sight of large objects isn't likely to be lost in PVIs. However, narrower and small objects such as trees, poles and road-signs are likely to disappear in PVIs. In perspective projection images, smaller objects close to a camera can occlude larger objects far from the camera.

EPI scheme is also an *overlapped-perspective projection* of scenes; overlapped and perspective along the camera path. Because of a lot of times overlapping, EPIs can provide 3-D information such as objects depth.

Fig. 7 shows PVI and EPIs which are generated from 5800 frame images acquired by the high-speed camera, HSV-500C[3] [10]. Five red lines are drawn in the PVI; each one indicating height of each epipolar plane for generating the corresponding EPI. (b), (c), (d), (e), and (f) are EPIs and the corresponding slope angle graphs. Height of EPIs comes down from (b) to (f). (g) is one of frame images. The PVI (a) are generated from 5800 middle vertical lines, escaping specular reflection in the right of the frame images.

2.3 Line-Scan Imaging

PVIs and EPIs are generated by concatenating specific line-images in each image frame; PVIs from specific vertical line-images and EPIs from specific horizontal line-images. A *line-scan camera* with lateral motion is enough to create PVIs or EPIs. Line-scan cameras are based on line-scan imaging technology and provide other benefit than area-scan cameras (frame cameras).

Perhaps the most common example of line-scan imaging is the fax machine. Line-scan imaging uses a single line of sensor pixels (effectively one-dimensional) to build up a two-dimensional image. The second dimension results from the motion of the object being imaged. Two-dimensional images are acquired line by line by successive single-line scans while the object moves perpendicularly past the line of pixels in the image sensor.

Line-scan imaging has some benefits, including (1) dynamic range that can be higher than conventional cameras, (2) smear-free images of fast moving objects, and (3) processing efficiency: line scanning eliminates the frame overlaps required to build a seamless image, particularly in high-speed, high-resolution applications.

2.4 Panoramic Street-Image

The *laser range finder* (LRF), used in line-scan imaging, realizes one more dimension. The third dimension results from the measurement of the distance up to objects. Three-dimensional images are also acquired line by line while the object moves perpendicularly past the scanning line.

When the line-scan sensor moves, instead of objects, perpendicularly to the scanning line, line-scan imaging is also realized and the same benefits can be received. Line-scan imaging system mounted on a measurement vehicle exploits its abilities, when it runs at a high speed in the outdoor environments. By using a line-scan camera, two-dimensional and seamless images are easily acquired, and on the other hand, a LRF generates three-dimensional and seamless images.

Panoramic street-image is defined as an image with the following characters. Panoramic street-image is a pair of PVI and EPI, or a pair of PVI and LRI. Panoramic street-image has 3-D information which is restorable from itself. by including an EPI or using a LRF. Panoramic street-image is based on line-scan imaging. Panoramic street-image is able to extract and restore 3-D information from itself.

3 Detection Using EPI Analysis

3.1 Epipolar-Plane Image Analysis

An epipolar-plane image is obtained from a sequence of images when a camera's optical center moves in a lateral motion. A point P of the scene, called *feature point*, draws a path in the EPI, referred as *feature path*. When a camera's velocity in its lateral motion is constant, all feature paths are straight in the EPI.

The image plane and the feature point P are at a distance h and D from the optical center's trajectory respectively. It is assumed that the velocity V of the loptical center is constant. The relationship between the depth D of the feature point P and the slope m of the feature path in the EPI is derived as the following equation,

$$D = h \times V \times m \ .$$

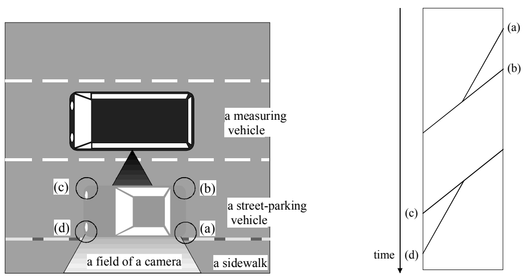


Fig. 3 Measuring situation and expected EPI

3.2 Algorithm Using Line-Scan Camera

Measurement and the corresponding EPI are shown in Fig. 3. Fig. 4 shows how to compute the depth of feature points from an EPI generated by a line-scan camera.

Firstly, the EPI is split by every several pixels in the direction of time, with no duplication and no gap occurring among all split small images. Second, feature paths in each split image are detected by using the Canny edge detector [8]. Each split image results in a binary image. Third, straight lines lying concealed in each split binary image are detected using the Hough transformation [11]. The strongest peak is only made a search for and selected, and then the corresponding straight line could be regarded as the most remarkable *feature path* in each split binary image. Finally, the *slope* of the selected *feature path* means approximately the *depth* of the corresponding *feature point* from the optical center at the moment the corresponding image was taken.

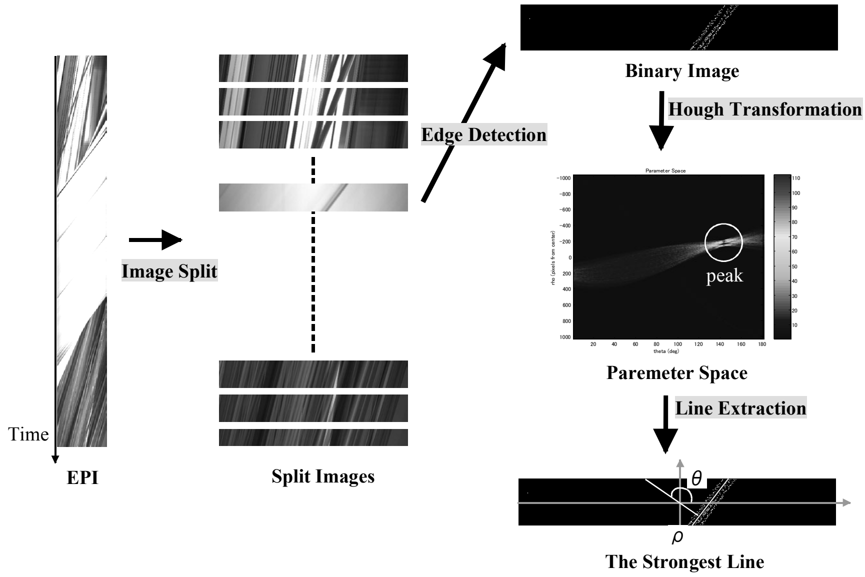


Fig. 4 Image processing diagram

3.3 Height of Line-Scan Camera

A line-scan camera should be set up to cut horizontally street-parking vehicles, so that the cutting plane is an epipolar plane. Its height decides what feature paths appear on an EPI. It is important to set a camera at the proper height so that certain vehicle's features, robust to vibrations, always appear on the EPI [9].

In order to examine how features of the vehicle's side appear in EPIs, EPIs with different height are generated from the images of the high-speed camera, HSV-500C[3] [10] with the frame rate of 500frame/s. Fig. 7 shows the EPIs and the depth curves.

The highest EPI (b) includes features on the background 'through the windows'. Those features have the depth different from the vehicle body's one, the corresponding depth curve is jaggy. The lowest EPI (f) has low-intensity light, and includes features on the wheels. The corresponding depth curve is smooth and flat.

Such features as backgrounds and wheels would susceptible to vibration and not be suitable for applying an EPI analysis, while features like vertical lines appear robustly in an EPI. The middle-high EPIs, (d) and (e), include the perpendicular lines, like the boundaries. The perpendicular feature lines remain nearly unaffected by vibrations.

4 EXPERIMENTS

4.1 Double line-scanning

Two line-scan cameras are installed on the measurement vehicle; one camera scans vertically and the other scans horizontally. By synchronizing these two cameras (Fig. 5), panoramic-view- and epipolar-plane- images are acquired simultaneously. We used DALSA SP-14-02k30 line-scan camera in this experiment. Both cameras scanned at the rate of 1 kHz.

Fig. 5 Two line-scan cameras mounted on the measurement vehicle: a upper camera scanning vertically, and a lower camera scanning horizontally.

We drove our measurement vehicle at 40 km/h along Housha-Route 21 in Tokyo, by using two line scan cameras, DALSA SP-14-02k30. The experimental results are shown in Fig. 6.

The detection results are summarized in a confusion matrix (TABLE 1).

TABLE 1

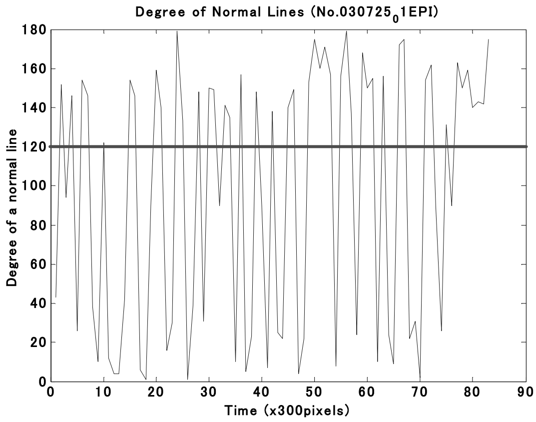
Confusion matrix of detection results

actual \ predicted	negative	positive
negative	N/A	1
positive	5	20

The accuracy of our method is 20 per 26 (76.9 %). Precision was 20 per 21 (95.2 %). True positive rate, or the recall rate was 20 per 25 (80.0 %). The detection rate was the 'accuracy' and was 76.9 %.

(a)

(b)



(c)

Fig. 6 Experimental results of double line-scan cameras; (a) panoramic-view-image, (b) epipolar-plane image, (c) depth curve calculated from EPI analysis, with a vertical axis as angle of normal lines, and a red line as a threshold value.

5 CONCLUSIONS

We introduced spatio-temporal volume image and two slice planes; panoramic-view- and epipolar-plane- images. Both images can be acquired simultaneously by using double line-scan cameras.

The detection method, based on EPI analysis, achieved higher detection rate, 90%. In addition, this method indicated its sensitive to height of the camera.

Future Work

In this paper, EPI analysis is based on only edge detection method. However, in the field of image processing technology, region methods are also studied and perform good results. Thus, we plan to merge both methods; edge and region methods, for achieving more robust results.

A laser sensor can measure the distance directly and robustly in the outdoor environment. However, an image sensor like a camera can provide much more information than the laser sensor. Thus, we plan to fuse the result from the image sensor and the one from the laser sensor, and improve the whole system. After extracting vehicles images from the panoramic street image, vehicle classification will be the next task.

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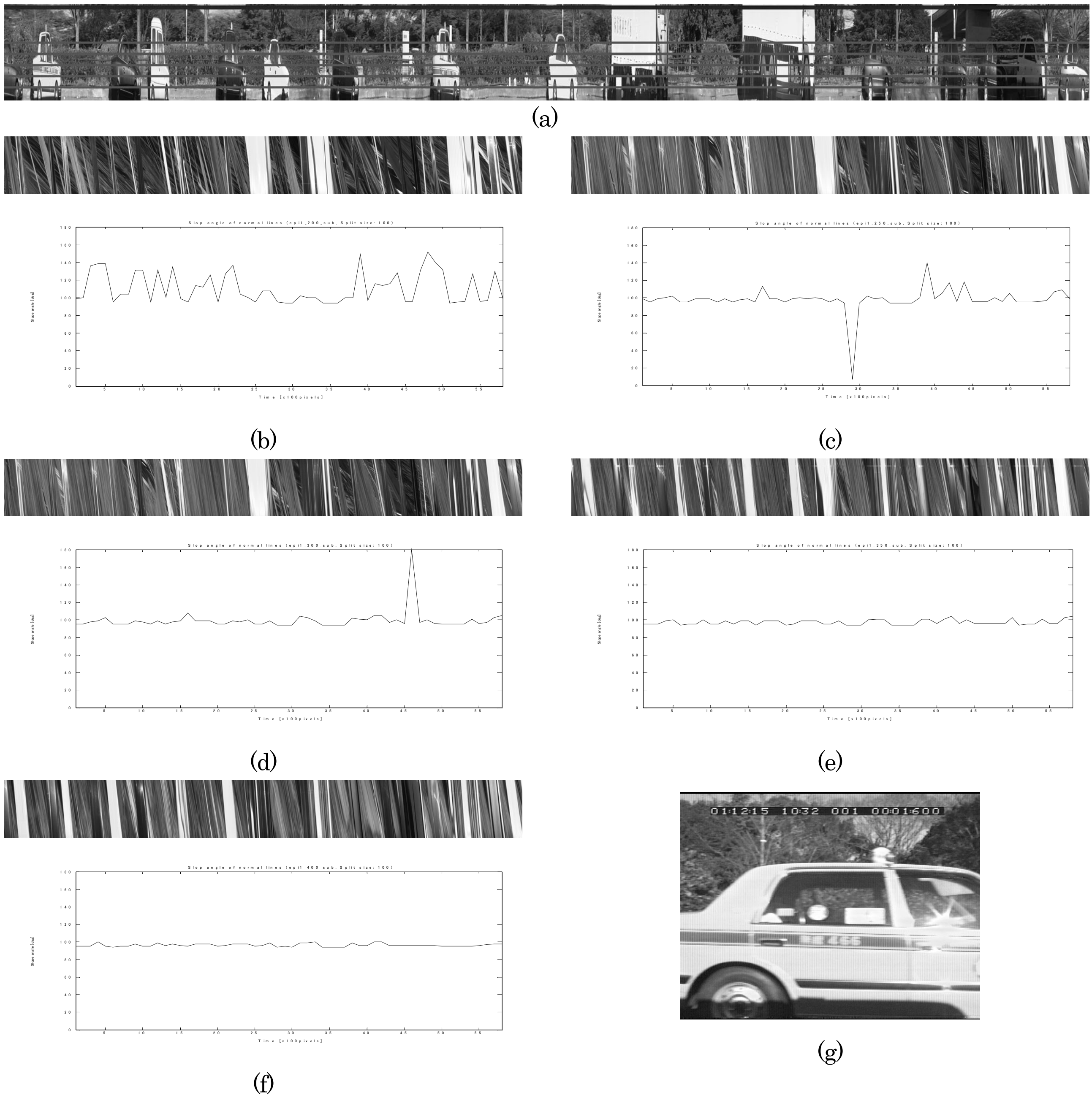

Fig. 7 Panoramic street image, EPIs, the corresponding slope-angle graphs, and a frame image. (a) Panoramic street image generated from 5800 frame images acquired by the high-speed camera, HSV-500C[3] and five red lines, each one indicating height of each epipolar plane for generating the corresponding EPI. (b), (c), (d), (e), and (f) EPIs and the corresponding slope angle graphs. Height coming down from (b) to (f). (g) A frame image. Panoramic street image (a) generating from 5800 middle vertical lines, escaping specular reflection in the right of the frame images.