IMAGE MATCHING ROBUST TO CHANGES IN IMAGING CONDITIONS WITH A CAR-MOUNTED CAMERA

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ABSTRACT

In this paper, we propose a matching method for images captured at different times and under different capturing conditions. Our method is designed for change detection in streetscapes using normal automobiles that has an off-the-shelf car mounted camera and a GPS. Therefore, we should analyze low-resolution and low frame-rate images captured asynchronously. To cope with this difficulty, previous and current panoramic images are created from sequential images which are rectified based on the view direction of a camera, and then compared. In addition, in order to allow the matching method to be applicable to images captured under varying conditions, (1) for different lanes, enlarged/reduced panoramic images are compared with each other, and (2) robustness to noises and changes in illumination is improved by the edge features. To confirm the effectiveness of the proposed method, we conducted experiments matching real images captured under various capturing conditions.

Index Terms— Image Matching, Car Mounted Camera, GPS, Panoramic Image

1. INTRODUCTION

A car navigation system is important for a smooth car-oriented society. For accurate navigation, the map should be up-to-date. However, most map information is updated on the basis of surveillance fieldwork.

Map information consists of two kinds: road and streetscape information. Road information is the structural information of roads (e.g., the locations of road markers and traffic signals, the number of lanes). Streetscape information provides the locations of stores/buildings that can be landmarks and destinations for drivers. Road information is scheduled to be compiled as a database by the government ministries. Therefore, if streetscape information can be also automatically updated by change detection in streetscapes, all the map information can be efficiently updated.

Methods for detecting a change in streetscapes, by comparing their images, have been proposed. One of the methods uses satellite images [1]. The change of a streetscape is detected by the difference between segments in the images that are captured in the same location at different times. However, some important information such as signs can't be obtained because the images are captured from the sky. On the other hand, [2] uses a car-mounted omni-directional camera and an off-the-shelf GPS. Since the sides of buildings are thus observed, information obtained by this method is more detailed than that obtained from satellite images. Image sequences observed in roughly the same location are first extracted from a number of images that are captured at different times with position information. Since the off-the-shelf GPS has a margin of error of about 15m, the images in the same location are extracted by image matching based on the DP matching between the sequences. The change in streetscapes is then detected by the pixel difference between the extracted images.

Since this method [2] assumes that an omni-directional camera captures images under convenient capturing conditions (i.e., high frame-rate capturing in a low car-speed), (1) a small change is difficult to detect because the resolution per area of the omni-directional camera is low, and (2) wide areas can't be observed simultaneously because image observation under the above conditions is not desired for public automobiles, that is, probe cars are required; it is impossible to secure a large number of probe cars in order to observe wide areas simultaneously.

Consequently, we propose a map-update system with the following features:

- Wide areas can be observed simultaneously by observation from a number of normal automobiles.
- The system assumes that each automobile has an ordinary low-resolution car-mounted camera, of the type which is often used in a drive-recorder, and an off-the-shelf GPS receiver.
- An automobile just captures images and sends them to a server system via wireless communication. The server system analyzes the collected images in order to detect changes in streetscapes.

As with the previous method [2], our system first matches previous and current images captured in the same location. Any change is then detected based on the difference between the matched images. However, our system has the following problems that need solving:

- An off-the-shelf GPS receiver has a margin of error of about 15m.
- Images at different times look different due to changes in illumination and other minute changes in the streetscape.
- Since images are captured from a number of normal automobiles, the images are asynchronized, the car speeds are different, and the framerate of the images is low due to wireless communication. These features result in the large difference in the image-capturing positions.
- Since images are captured by a cheap off-the-shelf camera, they are not suitable for image matching and change detection.
- Since the camera angles and the driving lanes are different among automobiles, the appearance of the streetscape in the images changes significantly.

While the first two problems are dealt with also by existent methods, the last three are our own system's own problems. We propose an image matching method that solves all the problems. This matching method must be robust to changes in capturing conditions that are due to observation by various car-mounted cameras at different times.

2. MAP UPDATE SYSTEM

In this section, we describe the details of the map update system.

This system collects the detailed streetscape information simultaneously and efficiently from a number of areas. Changes in streetscape are detected by using the collected information. For simultaneous wide-area observation, normal automobiles shown in Fig.1(a) collect information while running freely with a monocular camera and a GPS. The camera positions and the view direction are different for each automobile. The camera is assumed to be set in the back of the rearview mirror. Its view direction is pointed to the automobile's moving direction as shown in Fig.2. In Fig.1(b), the collected information (i.e., image, positioning information, capturing time, internal parameters of the camera, camera positions) is sent to the map update system via a wireless communication such as the cell-phone that is used by an existing map-delivery system [3]. Because of wireless communication, images must be compressed (e.g., JPEG) and low resolution (e.g., 640×480 pixel) in order to decrease data traffic. However, unlike an omni-directional image that captures 360-degrees view in a 360×240 pixel image, a normal camera can capture the detail of a streetscape (e.g., a store sign) even in a low-resolution image, as shown in Fig.3. If the imaging conditions are assumed to be the following, a maximum of 450KB of transmission occurs in 1 second. The file size of an image is about 100KB-150KB, and the framerate is 3fps. The bandwidth of a current cell-phone is about 269kbps. However, in the next-generation cell-phone it is 20Mbps in an experimental measurement. Therefore, if the above mentioned compressed images are received selectively from only several cars, it is possible for the server system to collect enough online the information to update a map. The system updates the map using the collected information as illustrated in Fig.1;

(1) The previous information database is compiled from input data.

(2) The system matches the previous and current image sequences that are captured in the same location.

(3) The change is detected by comparing the matched images.

(4) The map is updated based on the detected change.

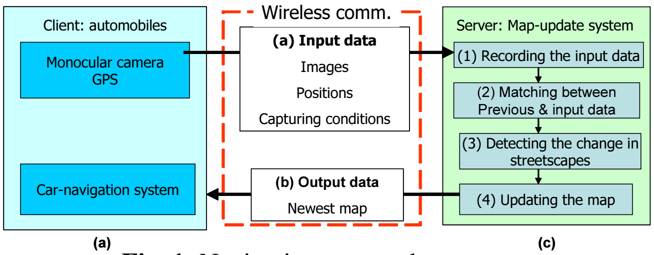

Fig. 1. Navigation map update system.

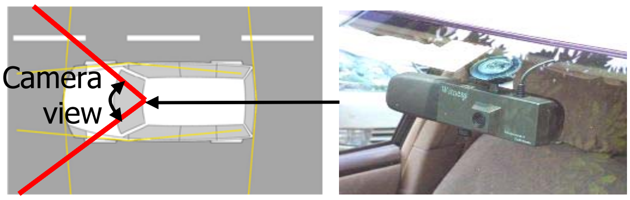

Fig. 2. Camera mounted in a car.

(a) (b)

Fig. 3. (a): Observed image in our system, (b): Omnidirectional image in [2].

3. IMAGE MATCHING ROBUST TO CHANGES IN THE CAPTURING CONDITIONS

3.1. Image Matching using Panoramic Images

In our method, by comparing these sequences that are extracted by the position information, previous and current images captured in exactly the same location are matched. However, in our system the capturing intervals are lengthened in order to send the images via wireless communication. Because of different car-speeds, the capturing timing is not synchronized among automobiles running on the same road. Even if the current image is compared with one of the previous images captured in the location nearest to where the current image is captured (Fig.4(a)), simply searching for an overlapping region between these two images is difficult because the region is small due to the long capturing intervals. Therefore, our method matches the images using their panoramic images. The panoramic image is created by connecting time-series images in each previous and current sequence. Since the overlapping region is large in the panoramic image, stable matching is possible even if the capturing interval is long and the capturing timing changes (Fig.4(b)).

The following image matching methods similar to our method have been proposed: (1) [[5]] creates a panoramic image by concatenating images captured at rest while moving a camera along a straight line parallel to a streetscape and stop at regular intervals, and (2) [[6] , [7] , [8], [9]] create a panoramic image by concatenating sequential isometric line-scanned images. [[6]] uses line-scanned images captured by a robot mounted camera. [[7], [8], [9]] use line-scanned images captured by a car-mounted camera. Furthermore, image blurring is rectified by using the estimated depth of an object in the panoramic image in [[9]]. In [[8]], a 3D textured urban model is generated by projecting observed line-scanned images onto a CAD model by using a laser range scanner. These additional procedures allow us to generate more informative panoramic images. However, all of these methods cannot deal with the different capturing conditions such as a moving speed and a camera angle. Differences in these conditions result in a corrupted panoramic image. As mentioned before, these differences inevitably exist in our map-update system.

Our method copes with these differences by (1) rectifying captured images based on camera angle and (2) adjusting the width of each image concatenated in chronological order based on camera speed. With the images thus rectified and adjusted, panoramic images acquired at different times can be similar. The similar panoramic images facilitate finding an overlapping region between them (i.e., facilitate matching the panoramic images).

As with a panoramic image, EPI (Epipolar Plane Image) analysis is a popular way to improve the robustness of analyzing an observation scene by connecting time-series images [10]. Several methods for a car-mounted camera have been also proposed. For example, 3D reconstruction and ar-

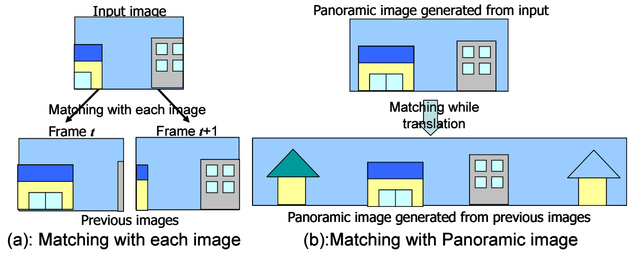

Fig. 4. Image matching.

bitrary view generation with an EPI image [11] and arbitrary view generation by matching EPI images of multiple cameras [12]. However, in our proposed system, normal automobiles often move unpredictably with undesired movements, for example, swaying up-down and left-right, and changing speed. These undesired movements make EPI analysis more likely to fail. The negative influence of these movements has been confirmed in [11].

The features for the matching are extracted from less-changed streetscape area that faces the car's lane. This is because the streetscape area has the characteristic features for identifying the capturing position. However, since the view direction is pointed in the direction that the automobile is moving direction, the streetscape areas are significantly distorted at the left side of the image of the streetscape, as shown in Fig.5. Although the camera points to the automobile's moving direction in our system, the camera should face the streetscape for observing the images suitable for identification. In order to create these images virtually, a part of the captured image is cut out and projected onto a panoramic image plane using projective transformation.

3.2. The problems occur due to the change in capturing conditions

For previous and current panoramic images matching, we should cope with the change in capturing conditions that occur due to various factors (e.g., the number and variety of automobiles and cameras, and different capturing times). In what follows we first describe (1) the change in capturing conditions that effect the appearance of the panoramic image and (2) how to cope with it.

(1) Changes in the view direction.

Since the view direction of cameras differ, the appearances of the images differ too, even if they are captured in the same location, as is shown in Fig.5(a) and (c).

The difference also occurs in the appearance of the panoramic image. Therefore, a virtual image is created from the captured image so that its view direction coincides with the automobile's moving direction. The view direction of a real camera is obtained with reference to the automobile's moving direction and used to generate the virtual image. The stability of the image matching can

Fig. 5. Images captured by different camera directions and in driving lanes.

be improved using the panoramic images that are created from these virtual images. In [6] also, a panoramic image is created from the images in which the roadside is observed. In this system, however, an undistorted panoramic image can easily be created by connecting high-frame-rate line-scan images observed by the fixed camera. On the other hand, for the panoramic image that is suitable for image matching, image compensation based on the camera rotation angle is required.

(2) Changes in the weather conditions

The illumination is greatly changed depending the capturing time. Because the capturing time is included in the capturing information sent from the client, image sequences captured at the about same time can be found. However, image comparing is difficult because of changes in brightness due to the weather conditions. In the existent method [2], the image matching is done by the DP matching that uses the color information in images. However, the color information is susceptible to changes in the weather conditions. If the illumination changes excessively in our system, the color information is not suitable for the features. Therefore, the images are matched by the edge features that are robust to the change in the illumination.

(3) Changes such as roadside trees and signs

Minor changes such as swaying roadside trees and minute complicated textures such as signs obstruct correct matching between current and previous images. These regions are therefore removed from the edge images. The generated edge images enable image matching using characteristic features (e.g., boundaries of buildings) robust to changes over time.

(4) Changes in driving lanes

If images are observed in different lanes, the appearance of the streetscapes there are also different because the distance between a camera and the streetscapes is changed, as shown in Fig.5(a) and (b). In order to match these images correctly, they are compared while changing their sizes.

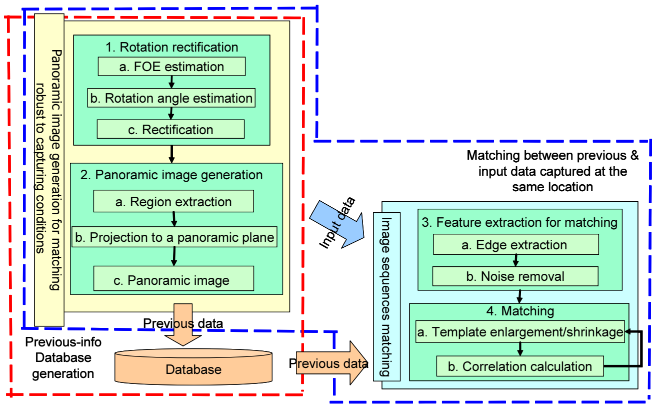

Fig. 6. Image matching process.

3.3. Image matching process

In this section, the image matching process is introduced briefly. Fig.6 illustrates the process flow of our method.

(1) Image rectification based on the camera rotation (Sec. 3.4)

1. **FOE estimation:** The FOE is estimated using optical flows shown in the observed images.
2. **Camera rotation estimation:** The rotation angle of the camera is estimated using the FOE.
3. **Image rectification:** Each observed image is rectified so that the images are captured while the camera is directed in the moving direction of the automobile.

(2) Panoramic image generation from an image sequence (Sec. 3.5)

1. **Region extraction:** A part of image (Hereafter, it is defined as the rectangle image) whose width is equal to the displacement is then extracted from the image.
2. **Image projection:** The rectangle image is projected onto a panoramic image plane parallel to the automobile's moving direction.
3. **Panoramic image generation:** The panoramic image is created by concatenating the rectangle images projected onto the panoramic image plane.

(3) Feature extraction for image matching (Sec.3.6)

Edges are extracted from the panoramic image. The noises are eliminated.

(4) Image matching (Sec.3.7)

For image matching, the various sizes of the current panoramic image are compared with all regions in the previous panoramic image.

3.4. Rotation Rectification

First, we describe how to estimate the FOE in images. When an automobile with the camera moves forward, the FOE indicates its moving direction.

In practice, the FOE is calculated as follows. First of all, several feature points are given manually in an image captured at time t. Each point is tracked in an image at $t+1$ based on correlation of its local image in order to calculate its optical flow. The feature point should be extracted in a streetscape region that consists of characteristic appearances and that is always visible from the camera. It is, however, difficult to estimate robustly the flow of a point near the image center in which a scene distant from the camera is observed, because its displacement between sequential frames is very small and leads is followed by a noisy flow. The flow around an outer region can be, on the other hand, robustly estimated because its displacement is large enough if the point correspondence between sequential frames is established. However, the large displacement results in difficulty in optical flow estimation based on point matching. In our method, therefore, the feature points are extracted around the mid point[1]. The flows of these points are computed based on their tracking results between N frames[2]. The centroid of the intersection of these flows is regarded as the FOE in the image at t.

If the optical axis of the camera coincides with the 3D line from the optical center of the camera to the FOE in the image plane, the image plane is considered to be perpendicular to the moving direction of the automobile. The rotation angle of the camera is represented by pan (θ) and tilt (ϕ) angles between the optical axis, and the 3D line is obtained by the following formulas:

$$\theta = \tan^{-1} \frac{f_x}{fl} \quad (1)$$

$$\phi = \tan^{-1} \frac{f_y}{\sqrt{(fl^2 + f_x^2)}} \quad (2)$$

, where fl denotes the focal length of the camera, which is known because all camera parameters required are sent with observed images from an automobile (2).

Each observed image is then rectified with the rotation angle of the camera. Fig.7 illustrates the plane consisting of the optical axis and the x axis of the image in a 3D coordinate system. Let virtual image plane B be perpendicular to the optical axis, while observed image plane A is rotated by θ and ϕ. To obtain a pixel value for each point b in B for generating a rectified image, the intersection, a, of A and the line that is determined by b and the optical center O_c is computed. The 2D coordinates of a in A can be calculated by rotating a by $-\theta$ and $-\phi$; the x-y coordinates of a 3D point, b, in B indicate its 2D image coordinates whose image center is at the intersection of the optical axis and B. a is rotated by the following rotation matrix. This process is performed for all pixels in B. As a result, the rotation-rectified image can be generated.

[1]In experiments shown in this paper, the feature points are extracted between $x = 120$ and $x = 170$ in a VGA image.

[2]In experiments shown in this paper, N is determined to be 3 because any point is observed at least through 3 frames in our captured image sequences.

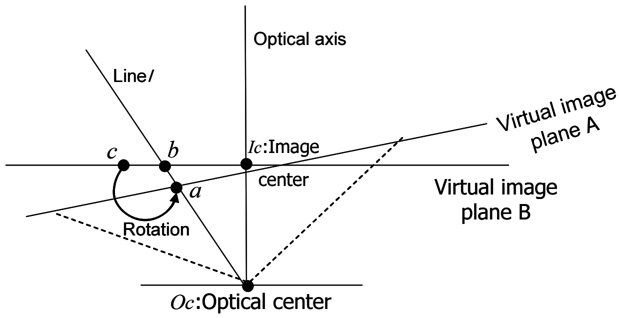

Fig. 7. Rotation rectification.

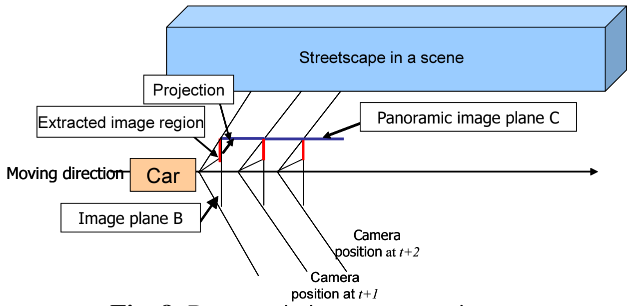

Fig. 8. Panoramic image generation.

$$R = \begin{bmatrix} \cos\theta & \sin\theta\sin\phi & -\sin\theta\cos\phi \\ 0 & \cos\phi & \sin\phi \\ \sin\theta & -\cos\theta\sin\theta & \cos\theta\cos\phi \end{bmatrix} \quad (3)$$

3.5. Panoramic Image Generation

A rectangle image is created by extracting a part of an observed image. The rectangle image is used for generating a panoramic image (Fig.8). If the rectangle image is extracted from an outer region, its appearance is deformed significantly due to perspective projection. This deformation makes it difficult to concatenate smoothly the sequential rectangle images for generating a panoramic image. Although the deformation around the image center is small, features suitable for image matching can't be obtained from this region because everything looks tiny. The rectangle image is, therefore, extracted from the mid point between the left side and the center of the image.

The width of the rectangle image should be determined by a horizontal displacement between two sequential frames for suppressing the gap between the sequential rectangle images. The displacement is determined by the horizontal component of optical flow, which is employed also for obtaining the FOE. However, while the FOE needs to be estimated once, unless a camera mounted in an automobile is moved, the rectangle image is extracted from all observed images. That is, feature

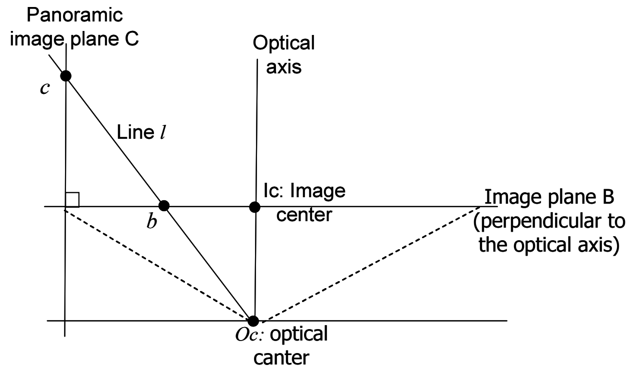

Fig. 9. Projection onto a panoramic image plane.

−1	−2	−1
−1	−2	−1
0	0	0
1	2	1
1	2	1

Vertical

−1	−1	0	1	1
−2	−2	0	2	2
−1	−1	0	1	1

Horizontal

Fig. 10. Edge detection operator.

points for determining the width of the rectangle image must be given automatically. The points are extracted using the Harris Operator [13]. To acquire a width robust to the noise in optical flow estimation, the median value of the flows of 100 points during three frames is used as the width.

A rectangle image is extracted from each observed (rotation-rectified) image as described above. As illustrated in Fig.9, rotation-rectified image plane B is perpendicular to panoramic image plane C. For the panoramic image that is suitable for image matching, all the rectangle images are projected onto a panoramic image plane that is considered to be perpendicular to a streetscape and concatenated in order of capturing timing. Let line l be determined by the optical center O_c and point c in C. By projecting the pixel value of point b in B that is an intersection of l and B into c, the panoramic image can be generated.

3.6. The features extraction robust to noise

In our method, edge features are employed for image matching because they can be extracted from an observed image robust to a change in illumination. Furthermore, the edges are modified so that they are suppressed in regions with minute complicated textures in order to focus on stably detectable features (e.g., boundaries of a building). The edges are extracted using a modified Sobel operator shown in Fig.10.

With the difference of pixels of a set which is at a distance from the notice pixel that are extracted by this operator, the edges with detailed textures (sings, roadside trees, etc.) are not extracted. Therefore, edges (e.g., contours of buildings) which abruptly divide areas are extracted (Fig.11). A threshold for edge detection is determined manually based on extensive experiments. Note that artificial edge lines might

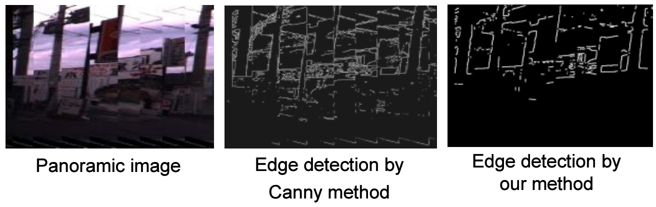

Fig. 11. Edge detection result.

arise along a boundary between rectangle images. The operator responds in this line. The artificial edge lines obstruct correct image matching. All long segments between the rectangle images are, therefore, removed. Additionally, denoising is applied to this extracted result. In denoising, if edges that exists in the eight-neighborhood of the notable edge is lower than the threshold, the notable edge is removed. As a result, edge features used for image matching are generated. Furthermore, the previous panoramic image is blurred by a Gaussian filter. This blurring is required for matching robust to minute differences between current and the previous images. The procedure of our feature extraction is summarized as follows.

1. Edges are extracted using a modified Sobel operator (Fig.10) from the previous and current images.

2. Artificial edges between neighboring rectangle images are eliminated from the edges.

3. Noises are eliminated from the edges.

4. The previous image is blurred by a Gaussian filter.

3.7. Image matching by enlarged/reduced images and translation

The image matching is performed using the previous and current edge panoramic edge images. In order to cope with the difference between these images due to observation from different lanes, correlation between the images is calculated as follows:

1. The current image is expanded and reduced to various sizes.

2. Each size of the current image is translated on the previous image for calculating the normalized correlation between them at each position.

The current image matches the part of the previous image in which the normalized correlation becomes maximum. Then, the left side image included in the current panorama image is matched with that in the matched part. In our method, the image size is changed between 0.5 times and 1.5 times at intervals of 0.1 times.

4. EXPERIMENTS

4.1. Experimental Environment

Experimental data has been collected for half a year in Nara, Japan. All the data was obtained by a monocular camera and an off-the-shelf GPS receiver. Two cars were used for data collection. The cars ran at 30-60 km/h. Although the camera was always set under a rearview mirror so that its view direction matched roughly the automobile's moving direction, the view direction changed slightly. The JPEG-compressed image size was 640x480 pixels. The frame-rate was 3-4fps. All internal camera parameters (i.e., image center and a focal length) were estimated using [14]. The GPS receiver got its location once per second. The location information was associated with images captured during the interval.

Taking into account an error of the GPS receiver (15m), current and previous panoramic images consisted of 9 and 32 sequential rectangle images (about 33m and 118m), respectively. Each matching result was manually examined to confirm whether or not the current image matched the previous image captured in the location in which the current image was captured.

4.2. Robustness to the change in the view direction of a camera

We observed the same scene twice by cameras directed from different angles, i.e., from car I and car II; a previous panoramic image was generated of one sequence that was captured by car II, and a current panoramic image was generated from the other sequence, captured by car I. Two kinds of the panoramic images were generated and compared for matching; (1) without rotation rectification and (2) with rotation rectification. Fig.12 illustrates the captured images before rectification and generation of the panoramic images, each of panoramic images was created from 25 frames. Although the images were captured in the same location and driving lanes, they differ greatly. As a result, the panoramic images also differ from each other. The actual image matching was executed using the panoramic image in the upper row in Fig.12 and the short panoramic image in Fig.12, which are the previous image and the current image, respectively. The matching result between the panoramic images is shown in Fig.13. White and red rectangles indicate the correctly matched region and the matching result.

The matching result using the rotation-rectified images is shown in Fig.14. The estimated rotation angles of the cameras in car I and car II were $\theta = -0.98°$, $\phi = -2.55°$ and $\theta = 5.23°$, $\phi = 0.41°$, respectively. It can be confirmed that there were few differences between the two panoramic images and the two captured images. The result of panoramic image matching after rectification is shown in Fig.15. A red rectangle indicates successful matching.

Fig. 12. Original observed image and a generated panoramic image.

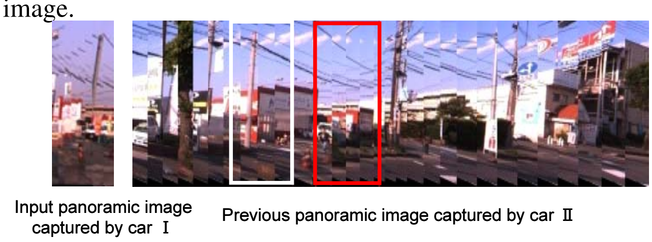

Fig. 13. Matching result using the original images.

4.3. Robustness to the other changes in capturing conditions

In order to confirm the robustness to the change under various capturing conditions (i.e., illumination, weather, road, change in a signs, and change in driving lane), image sequences captured in 10 locations were selected and compared for image matching. The number of sequential images used for generating previous and current panoramic images are determined taking into account frame-rate, car speed, and the errors by the GPS receiver; 320 frames (about 1185m) for the previous images and 90 frames (about 333m) for the current ones. The capturing conditions in each location were as follows:

(Location A) Illumination was changed due to different cap-

Fig. 14. Rotation-rectified image and a generated panoramic image.

Fig. 15. Matching result using the rectified images.

Fig. 16. Input and previous panoramic images captured at locations A and B.

turing times.

(Location B) The previous images were captured on a rainy day.

(Location C) The images were captured on an uphill slope.

(Location D) A sign (of a gas station) was changed.

(Location E) The images were captured in different driving lanes.

(Location F) The images were captured on a decline.

(Location G) A building was changed.

(Location H) The automobile changed driving lanes while the previous images were being captured.

(Location I) The images were captured on a curve.

(Location J) A bus was stopped on the road side when the previous image was captured.

The matching results are shown in Table.1; eight successful results and two unsuccessful. We can confirm the robustness to the changes in illumination (locations A and B), a scene (i.e., a sign) (location D), and driving lanes (location E), which is the objective in this paper. A part of successful results is shown in Fig.16. A red rectangle indicates successful matching. Two unsuccessful results were obtained at locations H and J. The results are shown in Fig.17. White and Red rectangles indicate the correctly matched region and the matching result. Since an undesired deformation occur in the previous panoramic image due to the lane change while capturing the images in location H, the matching failed. The obstruction of the bus resulted in the unsuccessful matching result in location J.

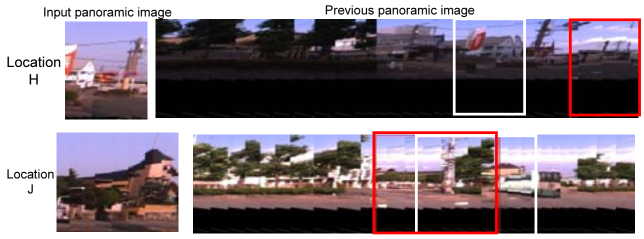

Fig. 17. Input and previous panoramic images captured at locations H and J.

We also conducted the above ten experiments using high and low frame-rate images (5 and 1.5 fps). With 5 fps images, as with 3 fps images, unsuccessful results were obtained in locations H and J. With 1.5 fps images, on the other hand, unsuccessful results were obtained in five locations, B, C, D, H, and J. The width of each rectangle image is greater in the low frame-rate images than in the high frame-rate images. This results in seam lines between wide rectangle images and the unsuccessful matching results.

5. CONCLUDING REMARKS

We proposed a method for matching streetscape images captured at different times by using a conventional low-resolution camera and an off-the-shelf GPS receiver.

In the future, with a pair of matched images that required by our method, changes in streetscapes are detected for an automatic updating a map. The changes should be detected not from a pair of panoramic images used for image matching but from the pair of matched (original) images, because they can't include any artifacts due to panoramic image generation.

To realize goal, the remaining problems below have to be solved:

Improving panoramic images: In the panoramic-image generation method proposed in [6], the generated image is seamless because spatially dense lines-scanned images are concatenated. In our system, on the other hand, seam lines arise in a generated panoramic image due to low frame-rate and wide rectangle images. Although the seam lines can be smoothed out if the 3D distance between the camera and an observed object is known [15], it is impossible to know the 3D structure in a wide area scene. In order to eliminate the seam lines, image transformation based on feature-points matching (see [16], for example) is required, as is the case with general panoramic image generation.

We should note that the same transformation in generating previous and current panoramic images is not guaranteed with image based transformation. Since it is difficult to match differently transformed images, more thought must be given to the effectiveness of the general panoramic-image generation

Table 1. Matching results.

Location	Capturing date and time	Result	Location	Capturing date and time	Result
A	Previous:2007/06/11 16:59	Success	F	Previous:2007/06/11 16:22	Success
	Current:2007/11/15 14:42			Current:2007/11/15 14:40	
B	Previous:2007/09/06 14:39	Success	G	Previous:2007/06/11 16:20	Success
	Current:2007/11/15 14:42			Current:2007/11/15 14:41	
C	Previous:2007/06/11 16:09	Success	H	Previous:2007/06/11 16:19	Failure
	Current:2007/11/15 14:32			Current:2007/11/15 14:40	
D	Previous:2007/06/11 16:22	Success	I	Previous:2007/06/11 16:59	Success
	Current:2007/11/15 14:43			Current:2007/11/15 14:42	
E	Previous:2007/06/11 16:22	Success	J	Previous:2007/06/11 16:15	Failure
	Current:2007/06/15 16:59			Current:2007/11/15 14:35	

method. In addition to the seams, the rough approximation of image change due to observation from different, which is implemented by simple image enlargement and reduction in our method, lanes also incurs an unsuccessful matching. This simple approximation produces an undesired image deformation because a real image is deformed based on perspective projection. Image mosaicing that copes with this problem may be required (see [17], for example).

Image change due to pitching: If a panoramic image is generated from images captured while an automobile shakes up and down, the neighboring rectangle images are not aligned properly. There is no harmful influence on image matching if all automobiles were to bound up and down in the same way due to bumps and holes in a road. However, an automobile's pitching is caused not only by road conditions but also by car conditions (e.g., speed/weight). Seamless image mosaicing that copes with pitching is required.

Robustness to extreme changes in weather conditions: In order to insure a successful image matching no matter how significantly weather conditions change, several thresholds for extracting edge features from a panoramic image should be adjusted automatically. In our system, however, all captured images do not have to be analyzed because a number of images in the same location are sent from different automobiles. That is, we should analyze whether or not a captured sequence is suitable for comparing with a previous sequence and/or whether a matching result is reliable. If not, the captured must be used for updating the map.

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