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Economical image stitching algorithm for portable panoramic image assistance in automotive application

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Abstract. In this study an economical image stitching algorithm for use in automotive industry is developed for retrofittable panoramic image assistance applications. The aim of this project is to develop a driving assistance system known as Panoramic Parking Assistance (PPA) which is cheap, retrofittable and compatible for every type of automobiles. PPA generates bird's eye view image using cameras installed on the automobiles. Image stitching requires to get bird's eye view position of the vehicle. Panoramic images are wide area images that cannot be available by taking one shot, attained by stitching the overlapping areas. To achieve correct stitching many algorithms are used. This study includes some type of these algorithms and presents a simple one that is economical and practical. Firstly, the mathematical model of a wide view of angle camera is provided. Then distorted image correction is performed. Stitching is implemented by using the SIFT and SURF algorithms. It has been seen that using such algorithms requires complex image processing knowledge and implementation of high quality digital processors, which would be impracticle and costly for automobile use. Thus a simpler algorithm has been developed to decrase the complexity. The proposed algorithm uses one matching point for every couple of images and has ease of use and does not need high power processors. To show the efficiency, images coming from four distinct cameras are stitched by using the algorithm developed for the study and usability for automotive application is analyzed.

Keywords: fisheye camera; image correction; matching points; verlapping area; image stitching

1. Introduction

Automobiles are essential transportation way in our modern life and the numbers in traffic are increasing day by day. This increase brings many traffic accidents. Because of that accidents which cause material and nonmaterial lost, drivers have started to place importance on the safety (Hughes *et al.* 2008). Many simple accidents occur because the position of the vehicle cannot be precisely estimated by the drivers. This lead to development of the imaging systems in the automotive industry.

Many of the accidents are caused by the inattentiveness of the drivers in the traffic. The drivers pay much more attention to the front of the vehicles they can easily see, but are careless to blind

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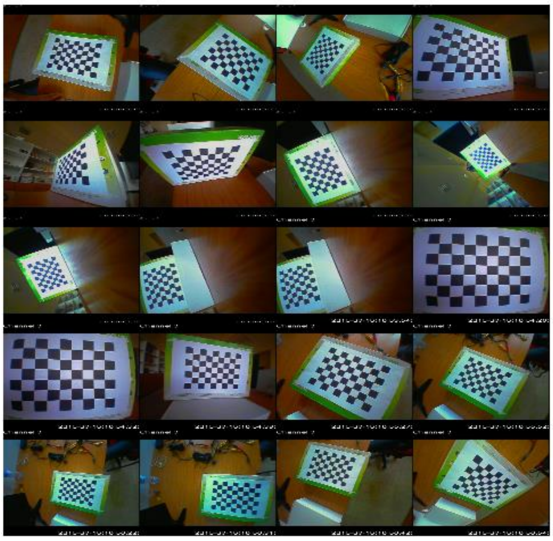


Fig. 1 The images used for calibration

points. This situation poses a danger for pedestrians especially for children (Cheng *et al.* 2013). Also, during parking, blind points can cause accidents resulting material damage. To solve these problems and to make the blind zones visible, the idea of installing cameras and stitching the images have been implemented (Stenkula 2009, Friel *et al*. 2010).

Many studies can be found in the literature on image processing involving parking assistance applications. Ehdlen and Pajdha (2007) advice installing four omnidirectional fisheye cameras to a truck. They represent a method which divides the overlapping areas many times to get stitched final image. Liu *et al.* (2008) have installed six cameras to surrounding areas of a vehicle and have tried a one-dimensional stitching algorithm. The automobile manufacturers produce such systems. For examples, Nissan product name is Around View System while Honda titled Eagle View and finally, Delphi Automotive's product provides 360º Surround View System with Parking Guidance. All these systems are embedded to the car computer systems and inherent to vehicle models.

In this study, an algorithm developed for a system that generally called as Panoramic Parking Assistance (PPA) which gives the bird eye view of a vehicle. It is aimed that, this system should be retrofittable and suitable for long and wide vehicles such as trucks and buses. Most manufacturers put this bird eye view systems on the especially higher segment models. The objective system, would be convenient for every vehicle segment. This is the major advantage of this system. Of course, there are some problems come with a portable system such that cameras are moving and their lateral positions and altitude are not known. Proposed algorithm allows retrofitting of cameras independent of vehicle size. By retrofitting it is meant that the cameras are not preequipped on the vehicle and their positions are free. Naturally the cameras will be fixed to the vehicle, but the positions of the cameras are arbitrary. But, these problems can be solved with correct calibration.

The paper is organized as follows, Section 2 includes the calibration work for the fish eye cameras. Section 3 includes the stitching study by using the SIFT and SURF algorithms. The need of a new algorithm is concluded in this section. Also, in Section 4, the proposed algorithms are told and four images are stitched to show it has succeed. Finally, the summary and the final comment on easy and low cost stitching job are included in Section 5.

2. Camera calibration and image correction

In this section, the mathematical model of the fish eye cameras used in the study are derived and using the model, distorted images taking from the cameras are corrected.

The correction is done by retaining the parameters of the camera. This work can be called as calibration. Camera parameters can be divided into two parts; intrinsic and extrinsic parameters. Intrinsic parameters are the focal length of the camera, f, coordinates of the central pixels, r and θ, while extrinsic parameters are used to describe the transformation from three-dimensional world coordinates to two-dimensional image coordinates. The extrinsic parameters provide the orientation and the position of the camera and it can be said that the extrinsic parameters are all related to camera pose (Li and Tsai 2010). The calibration of the fish eye camera is performed by using the software, Camera Calibration Toolbox of MATLAB. Camera Calibration Toolbox uses the calibration method developped by Zhengyou Zhang. Zhang (2000) defines the camera model as follows.

$$s\widetilde{m} = A[R \;\; t]\widetilde{M} \tag{1}$$

Where, $\widetilde{M}$ represents the three-dimensional world coordinates of a point, $\widetilde{m}$ represents the two-dimensional image coordinates of the same point. s is the scale factor. R and t are the extrinsic parameters of the camera and referred to rotation matrix and translation vector, respectively. Finally, A is a matrix that includes the intrinsic parameters of the camera. All of these parameters vary of each camera and for each camera the calibration must be performed and the model given in Eq. (1) should be formed individually. The cameras can be modeled by using many types (Hughes *et al*. 2008a). The polynomial model is used as the camera model in this study. The equation of this model is given in the following.

$$x_u = x_d(1 + k_1 r + k_2 r^2 + k_3 r^3) \qquad + \text{t.d.} \tag{2}$$

$$y_u = y_d(1 + k_1 r + k_2 r^2 + k_3 r^3) \;\; + \text{t.d.} \tag{3}$$

$$r^2 = x_u^2 + y_u^2 \tag{4}$$

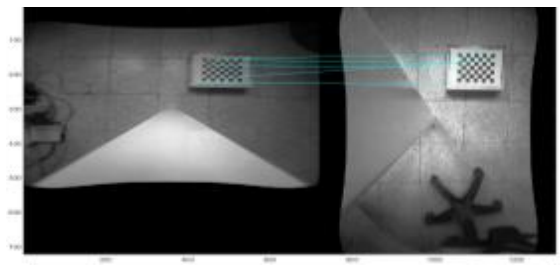
(x_d, y_d) is the image coordinate of a pixel in the distorted image taken from the cameras, and, (x_u, y_u) is the same pixel but in the corrected image. r as you guest, is the distance from corrrected pixel to the central pixel. (k_1, k_2, k_3) are the coefficents that can be obtained after the calibration work. The fish eye cameras can cause two types of distortions. The mathematical expressions in Eqs. (2)-(3) are referred to radial distortion as t.d. states the tangential distortion. But the effect of the tangential distortion is negligible (Hughes *et al.* 2008b).

Four fish eye cameras have 160^{o} field of view and gives images at 576×720 pixels are used to take images. To calibrate the cameras more generally, the checker board images taken with different poses are used. Fig. 1 shows the images of a checker board to be used in calibration process. The aim of using these different poses images is establishing a relation of selected points by getting how to change with the poses, and then calculating the coefficients.

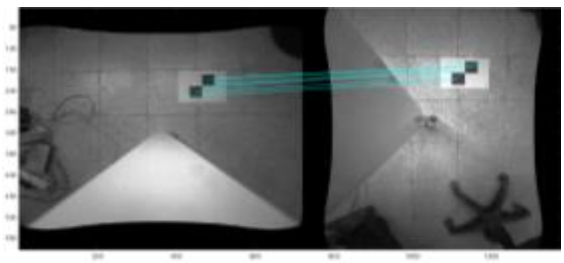
After the calibration the coefficients obtained for each cameras are given in Table 1.

Table 1 Camera coefficients

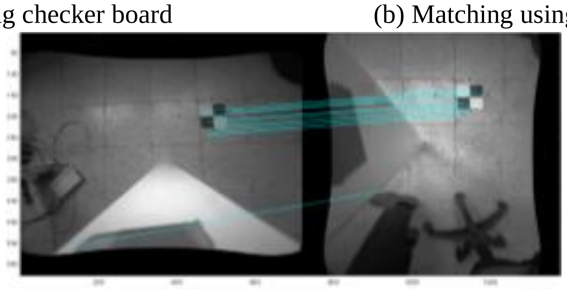
	k_1	k_2	k_3
Camera 1	0.1947	-0.2086	0.0519
Camera 2	-0.3176	0.0921	-0.0019



(a) Matching using checker board



(b) Matching using two black squares



(c) Matching using black - white squares

Fig. 2 Matching points using SIFT with distinct patterns

3. Image stitching using SIFT and SURF

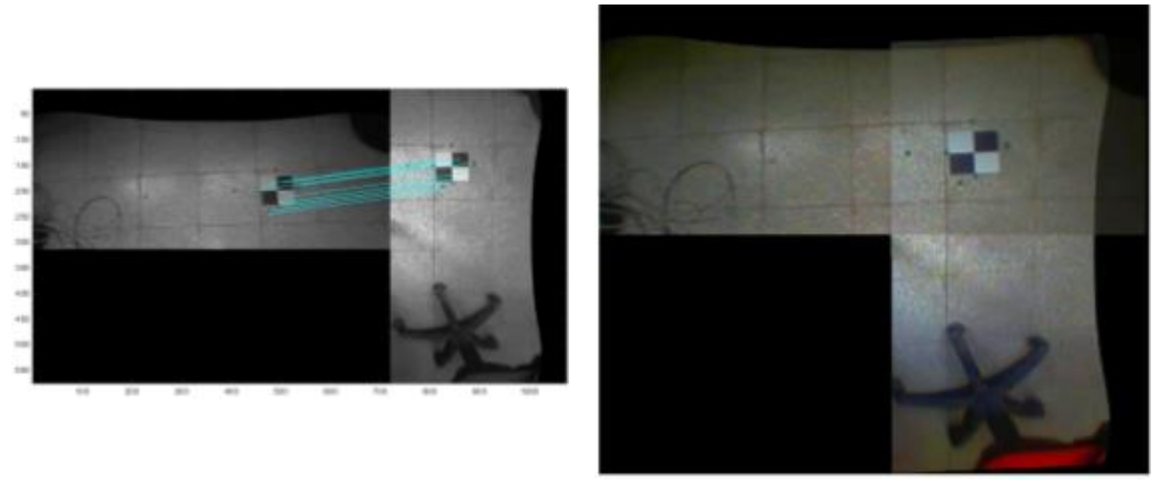
In this section, using SIFT and SURF algorithms matching points on overlapping areas are obtained and a panoramic view is tried to perform.

3.1 Stitching using SIFT

Scale Invariant Feature Transform, shortly SIFT is an algorithm to detect the features of images, firstly published in 1999 by David Lowe (2004). In general, it is used for the aims of object recognition, 3D modelling, video tracking. SIFT is also used for stitching images (Brown and Lowe 2007).

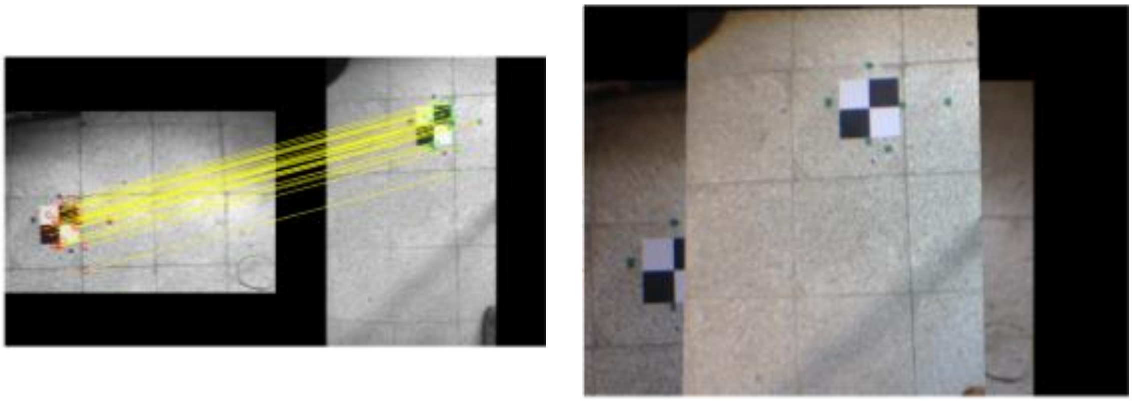
In this study, SIFT algorithm is used to obtain matching point. There are two images captured by fish eye camera and corrected as told in Section 2. Fig. 2. shows these images and matching points obtained by SIFT using distinct patterns. As you see, using the pattern has bigger white and black squares increase the performance of SIFT algorithm to match better when low cost and low-resolution cameras are used.

Fig. 3 shows the matching points of interested region. Using the black-white pattern all the points are obtained correctly. These points are used to obtain rotation matrix which is a filter to evaluate panoramic image. After, filtering two images the final stitched image can be seen also in Fig. 3.



(a) Matching points using SIFT (b) Obtained panoramic image

Fig. 3 Pixel matching and stitched image using SIFT



(a) Matching points using SIFT (b) Obtained panoramic image

Fig. 4 Pixel matching and stitched image using SURF

In conclusion, SIFT is a successful algorithm to stitch images of low resolution.

3.1 Stitching using SURF

Speeded Up Robust Features, shortly SURF, is also an algorithm to detect features of images. As an alternative of SIFT, the algorithm is represented by Herbert Bay (2008). The algorithm is intensively used for object recognition and 3D modelling.

The matching points obtained by the SURF are given in Fig. 4.

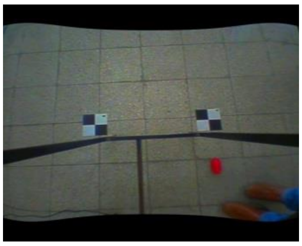
As seen, there are less matching points from SIFT solution. The compatibility between the matching pixels effects construction of the rotation matrix. The points obtained by SURF are not enough compatible that the stitching is failed.

In conclusion, SURF accomplishes to find out matching points but it is not a successful algorithm to stitch images of low resolution.


(a) The fish eye camera


(b) Digital video recorder (DVR)

Fig. 5 The cameras and DVR used in the study


(a) The front view


(b) The left view


(c) The right view


(d) The rear view

Fig. 6 The images to be stitched

4. Image stitching with single matching point

It has been concluded that the algorithms with higher complexity can stitch the images to get panoramic view. But, they succeed it when there is a remarkable pattern. Moreover, to stitch the images, they are filtered by the rotation matrix, this is a heavy job to product and sum pixel by pixel and this can cause time delay in real time systems. Also, to implement the panoramic system using these types of algorithms, high quality cameras and processors are needed. It increases the cost so that this system is not used in every type of vehicle.

In this section, the algorithm developed for the panoramic view system, which is retrofittable, and has low cost processors are introduced. This algorithm needs only one matching point for one pair of images. The performance of this algorithm would be observed on matching four images.

The stitching with single matching point uses some assumptions such that, it is assumed that the cameras installed on the vehicle is fixed and always give the same rotation and poses. Thus, the

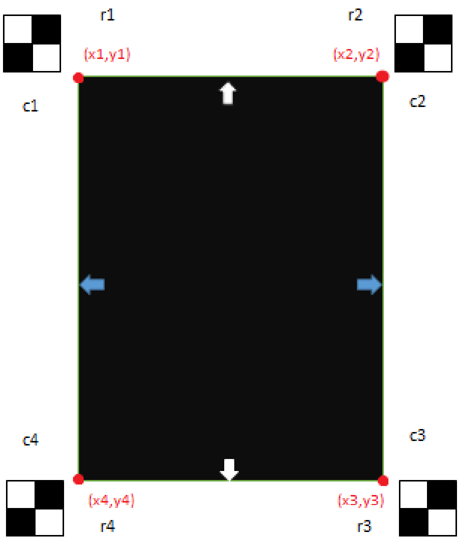
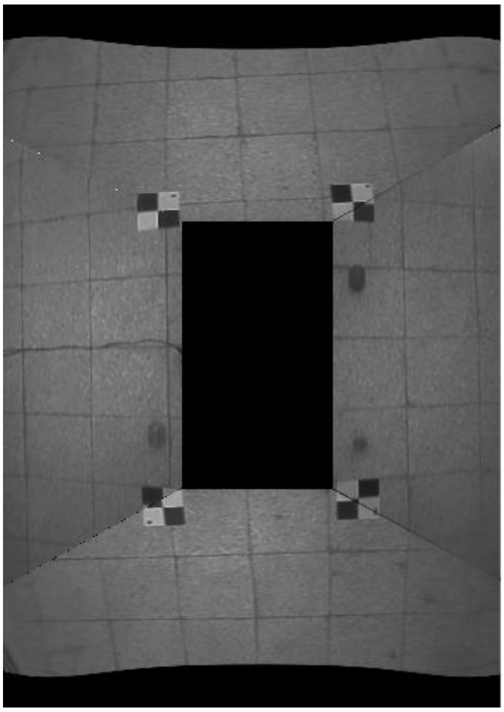
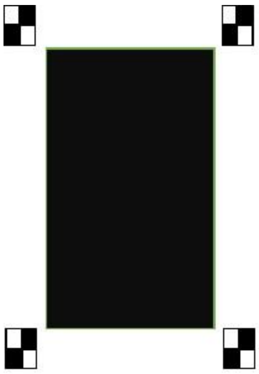


Fig. 7 The target stitching drawing



(a) The stitched image



(b) The target drawing

Fig. 8 The stitched bird eye view image and the target drawing

final stitched image pixel coordinates can be saved in a lookup table so that, the coming images can be easily stitched with once the cameras are calibrated.

In this study, the cameras have a resolution of 576×720 pixel and 160° field of view, is installed on a table as it is done for vehicles. The cameras give analog images and a Digital Video Recorder (DVR) is used for the transportation into the digital media. These devices can be seen in Fig. 5.

Fig. 6 shows corrected the images captured by the fish eye cameras. As seen, there are some regions that are not used for stitching caused by the wide view of the fish eye cameras. These regions are cut and only the regions of interest are used. The previous study (Demiryürek and Kutluay 2016) showed that larger patterns increase remarkability for low resolution images. So, a 2×2 black and white square pattern is used. Fig. 7. shows the target stitching drawing. (x_n, y_n) (n=1,2,3,4) is the matched pixel coordinate for every couple of images. r_n, is the distance from the row coordinates of matching points to the first (1st pixel) or the last (720th pixel) row pixel. c_n, is the distance from the column coordinates of matching points to the first (1st pixel) or the last (576th pixel) column pixel. The values are defined as follows.

$$r_{1,2} = x_{1,2} - 1 \tag{5}$$

$$r_{3,4} = 720 - x_{3,4} \tag{6}$$

$$c_{1,4} = y_{1,4} - 1 \tag{7}$$

$$c_{2,3} = 576 - y_{2,3} \tag{8}$$

We know that the vehicles are symmetrical and the cameras are aligned in the same direction with each other. So, with easy calculation one can reveal the follows.

$$r_1 = r_2 \tag{9}$$

$$r_3 = r_4 \tag{10}$$

$$c_1 = c_4 \tag{11}$$

$$c_2 = c_3 \tag{12}$$

These values give any information about how the images are divided and stitched. The stitching angle (α), is one of these. The stitching angle determines the ratio of the overlapping region between the image couples.

$$\alpha_{12} = \tan^{-1}\frac{r_1}{c_1} \tag{13}$$

$$\alpha_{34} = \tan^{-1}\frac{r_3}{c_3} \tag{14}$$

For instance, if α_{12} decreases, the front camera contributes much more than the side ones to the overlapping region on the front view. Similarly, if α_{34} decreases, the back camera contributes much more to the overlapping region on the rear view. Obtaining the matching point is very important issue. The wrong choices can cause wrong stitching. To construct the rotation matrix at least three point is required. But, this algorithm only requires on matching point and it only requires correctly matched point. The steps of this algorithm are as follows.

1. Obtain matching point for every two image, (x_n, y_n) , $n = 1,2,3,4$
2. Calculate r_1, r_3 and c_1, c_2,
3. Determine which camera should contribute much more, (α_{12}, α_{34})

4. Using the calculated values determine the region of interest,
5. Mask the images
6. Simply, sum the final images.

This algorithm includes except obtaining matching point, simply summing, subtracting, cropping and masking. There is no need for constructing rotation matrix and this is very fast in comparison. This is an advantage for an economical system.

The stitching of four images is executed by using this algorithm and the final panoramic image can be seen in Fig. 8. It is a successful stitching job. But, as seen from figure, the left side is better than the right side because of the chosen compatible matching point. In addition, the lines in the overlapping region can be eliminated by using median filter (Jahne 2005). Median filter, changes the central pixel's value with the average of the n×n neighbourhood pixel values. As n increases, the line gets lost but image is distorted. In this study 3×3 neighborhood is chosen and according to the stitched image resolution the clarity of the boundary lines is acceptable.

5. Conclusions

In this study, an image stitching algorithm is developed to obtain the bird eye view of vehicles surrounding areas for a panoramic parking assistance which is cheap, retrofittable and compatible with every type of vehicle. The well-known stitching methods such as SIFT and SURF were used but it is seen that these algorithms include high level processes and requires high power processors, this increases the implementation costs. The proposed methods are easy, clear and applicable. It is seen from the final stitched image that this method only requires the matching points which must be correctly detected. The empty pixels occur in the boundary but can be eliminated by a simple method, median filtering. Nevertheless, the pattern contains black and white squares enhances the remarkability to detect the matching points.

In conclusion, the proposed method is suitable for an economical bird eye view parking assistance since it includes simple summing and cropping operations on pixels and it only requires one matching point for every pair of images so there is no need for the rotation matrix which decreases the computational complexity. It can work with low resolution cameras and any cheap image processors so the single point stitching method is applicable for a retrofittable and economical system.

Acknowledgments

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