Automatic Image Stabilization for Omni-directional systems

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Abstract

The mobile catadioptric system is usually prone to vibrations, which cause the distortion in the transformed panoramic image. The goal is to find proper parameters of the mirror border to image stabilization. Fast method with sub-pixel precision is needed. This paper deals with methods which are based on the circle detection by using extracted border points. Several methods for edge detection is used, tested on real images and the results are discussed at the end.

1. Introduction

Omni-directional systems serve for recording meetings, surveillance, are used as vision sensors for mobile robots and so on. The system is usually based on standard video camera equipped with non-planar mirror that allows capturing a large portion of the space angle. The camera mounted to the holder with mirror is prone to the vibrations. The system Fig. 1 a), for which was developed stabilization method, is designed to be installed on the table to record participants sitting around. The transformation of the captured image is necessary before its further processing. The vibrations cause distortion in the transformed image. The captured image will be called the “omni image”. Parameters for the transformation are computed from this image. It has circular shape Fig. 1 b), which is given by the mirror border from camera view. The transformation algorithm uses information about circle center and radius. The omni image consists of simple background and circular mirror image, which well separate the circle border. The proposed algorithm finds parameters of the circle (center coordinates and radius). The sub-pixel accuracy is required by the reason of the undistorted transformation.

Various methods for circle detection exist. The Circle Hough Transform (CHT) has become a common method for circle detection in numerous image processing applications. Various modifications to the basic CHT operation have been suggested [7]. The large amount of storage and computing power required by the Hough Transform are the major disadvantages of using it in real-time applications. Zelniker, Vaughan, Clarkson [6] present an interpretation of the Maximum Likelihood Estimator (MLE) and the Delogne-Kasa Estimator (DKE) for circle-parameter estimation via convolution. For the MLE, the output provides a coarse estimate, but in order to obtain sub-pixel accuracy, it is possible to refine the coarse estimate through the Newton-Raphson method to achieve sub-pixel accuracy. A comparison of the MLE Newton-Raphson method to the DKE least squares method shows that the MLE performs better results as the arc length gets smaller and as the noise level gets larger.

Fig. 1 a) omni-directional system b) image from this system

A prior knowledge about an image let us use specific methods for circle finding. It is not necessary to search whole image space for possible circles. The radius and also the center of the circle vary in narrow interval. It allows specifying the chosen interval of these parameters for searching circle in the image. The methods for sub-pixel circle detection for mirror border parameter estimation are proposed at the beginning of the paper. The second part consists of tests and evaluation of these methods. The results are discussed at the end of the paper.

2. Proposed methods

The aim was to develop stable and fast algorithm for sub-pixel circle detection and parameter estimation. This paper presents three methods with their evaluation and mutually comparison. The first basic method uses sobel edge detector for border circle detection. The second part proposes modified canny edge detector. The third interpolation method is used to get better sub-pixel accuracy. The aim is to evaluate accuracy when are not used sub-pixel modifications as interpolation. The main idea of the circle detection is included in all modifications. Extracted border pixels serve for parameter computation by using iterative linear regression method [4]. The prerequisites are n measured points with x_i, y_i coordinates and the output is middle of the circle x_0, y_0 and the radius r.

Most of cameras have rectangular shape of CCD chip points, which means that image pixels have rectangular shape. This parameter is specified as aspect ratio. If aspect ratio is different from one, the resulting image is deformed. We must consider this when the input pixels are processed. The standard DV cameras have aspect ratio 54/59. Nowadays, the high definition cameras are already available. The higher resolution is very useful for superior transformed images. Aspect ratio at these cameras is usually 3/4.

1.1. Simple edge detectors

The basic method tries detecting border pixels by using Sobel or Laplace operators. The starting position of the circle inside the omni image is adjusted to the image center. The circle border is then searched inside the area between two circles, see Fig. 2. These two circles define deviation from the initial searching position.

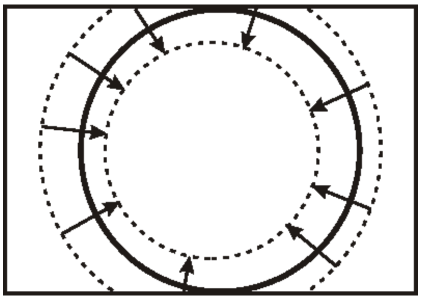

Fig. 2 Finding circle bordur

The circle border is tested in the direction from outer to inner area border, because the image background do not consist generally any edges.

Scanned area is splitted into *N* parts. The circle border is randomly tested inside each part *M* times. Results consist of *M*N* positions of the detected border. The iterative linear regression method is used for circle fitting from which are computed information about circle center position and radius. The iterative method for circle detection is used to increase the accuracy. The size of the searched area is decreased in each step. The circle properties are newly computed in each step from set of detected edge points in searched area. This approach allows searching circle position in bigger area then finding it in one step.

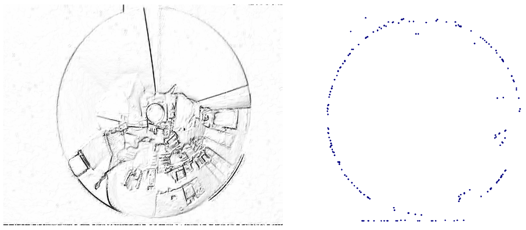

Fig. 3 a) Sobel edge detection b) detected border pixels

The area decreasing provides removing of false border points. This approach has in some cases unreliable results, which are given by bigger count of spurious edges. The precision of this kind of detection is around ±0.5 pixel. Such precision is enough for initial calibration, but it is not enough for automatic image stabilization.

1.2. Modified Canny edge detector

With some prior knowledge about an image, it is possible to use edge orientation information. The edge detection must be done for all directions in the first method. It causes occurrence of noise edges with directions which are not perpendicular to circle radius. One way to remove spurious edges is to use only one directional edge detector, which is possible, when the omni image is transformed to the panoramic view.

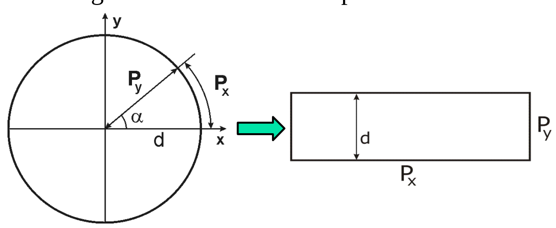

Fig. 4 Simple unrolling transformation

Shape of the panoramic image is rectangular and outer border of the circle is transformed as line in ideal case. This property is used for edge detection algorithm which applies only one directional Sobel operator. Simple unrolling algorithm is used to transform the part of omni image into panoramic view. The transformation of the output coordinates to coordinates of the captured image is following:

$$x_M = (d - P_y) * \cos\alpha + CenterX$$
$$y_M = (d - P_y) * \sin\alpha + CenterY \text{ ,}$$

where angle is $\alpha = \frac{P_x}{d}$. The height of the output image depends on the size of tested area around probable circle border. The output of the transformation is on the Fig. 5 a). Part b) contains image, where the vertical edge detection is applied on the transformed image a). The iteration process is demonstrated in Fig. 6. The transformed circle border is in ideal case projected as line.

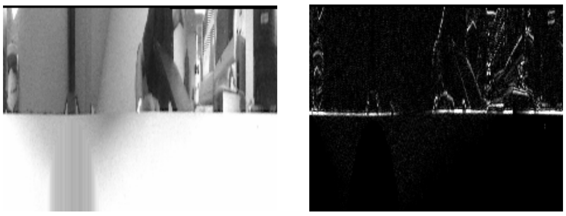

Fig. 5 a) Grey transformed image b) edge image

The transformation allows using methods which enable better extraction of the circle border. This modification improves accuracy, because only perpendicular edges to circle radius are extracted. The output of the edge detector is not thin edge. It must be further processed to get exact position of the edge.

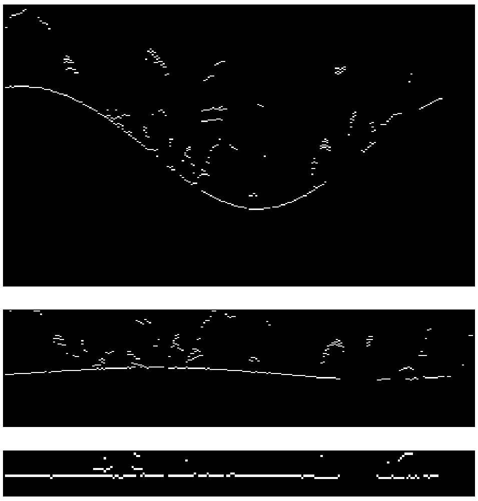

Fig. 6 Iteration process

The modified canny edge detector Fig. 7 was used for this purpose. The first and most obvious advantage of this method is low error rate. It is important that edges occurring in images should not be missed and that there should be no responses to non-edges. The advantage is only one response to a single edge.

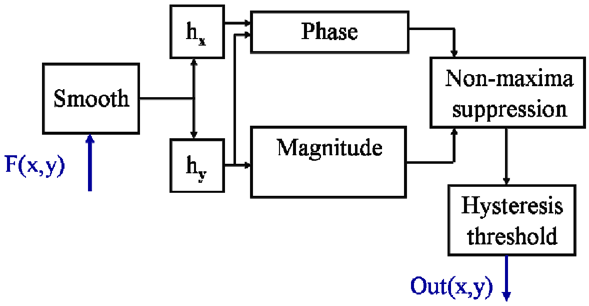

Fig. 7 Modified canny edge detektor

Fig. 7 depicts modified scheme of a canny edge detector. The modified edge detector firstly smoothes the image to eliminate the noise. Gradient map is computed for both directions, because it is used for phase computation. However, the magnitude is computed only from the vertical gradient map. The second modification is made for non-maxima suppression which eliminates among others the vertical edges.

The other advantage of transformation technique is computing edge map with various resolution. The resulting transformed image can have various number of columns which represent perpendicular lines to circle border. The weighted average of neighbor pixels is used when the image is transformed. This can significantly speed up proposed algorithm as can be seen in the graph Fig. 10. In section 3, the evaluation results and tests are presented. The results show that the detection works relatively precise with respect to lose some quality by transforming the image.

1.3. Derivative edge detection

The problem of finding the exact position of the edge is treated like a classical extremum problem. This means that the derivative functions have to be calculated. To get a high precision determination of the edges, an interpolation is suitable to use. For this purpose the cubic interpolation was chosen. The technique is used to create a continuous function out of the sample values.

The used equation is:

$$y(n) = a_0 t^3 + a_1 t^2 + a_2 t + a_3 \qquad (1)$$

with following definitions:

n = index of current sample (0 .. N-1)

y = interpolated value, $t = \frac{n}{N}$

$$a_0 = \frac{-t^3 + 3t^2 - 3t + 1}{6} \quad (2)$$

$$a_1 = \frac{3t^3 - 6t^2 + 4}{6} \quad (3)$$

$$a_2 = \frac{-3t^3 + 3t^2 + 3t + 1}{6} \quad (4)$$

$$a_3 = \frac{t^3}{6} \quad (5)$$

Firstly, the position of the zero second derivation must be computed. The point, where is the second derivation equals the zero, is called point of inflexion. The equation for computing position of this point on the curve is following:

$$t = \frac{2y_1 - y_0 - y_2}{-y_0 + 3y_1 - 3y_2 + y_3} \quad (6)$$

The algorithm for curve interpolation uses four values – two on the left and two on the right. The direction of the curve for which is computed the edge must be coincident with the radius of the tested circle Fig. 2. The line intersects horizontal/vertical curves, which are also interpolated from pixel values Fig. 8. The final curve is computed from four intersected points. Values of these points are substituted to equation 1.

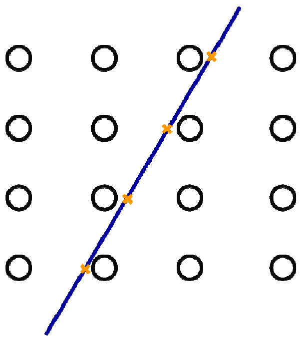

Fig. 8 Searching of the intersection with radius line

To know the exact position of the positive or negative edge, the zero-crossing position for the function has to be determined. The problem is to specify whether extract positive or negative edges, because it is hard to determine the relation between mirror image and the background.

3. Evaluation

The real sequence from meeting was used for testing. The system was installed in the room with varied background and was situated on the table. The goal was to verify accuracy for three implemented methods. For this purpose was used video-sequence with stable mirror.

Method	*Standard deviation*		
	x	y	radius
Simple	*0,5938*	*0,2429*	*0,4758*
Canny	*0,0741*	*0,0554*	*0,0767*
Cubic	*0,0544*	*0,0689*	*0,0555*

Tab. 1 Accuracy of tested methods

The first simple method do not transform input image, but only uses edge map for finding border points in given distances from tested circle center. The second method transforms part of the image on which use modified canny edge detector. This detector achieves very good results despite of waste of some information at the transformation process Tab. 1. The third method has good precision in the edge detection, but the problem is in edge localization Fig. 9.

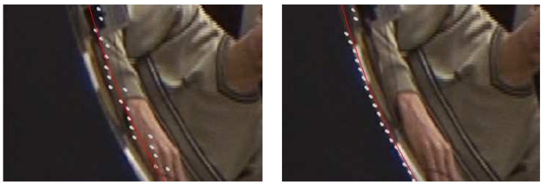

Fig. 9 Detection of the false circle border points

The solution is to use other method for finding the circle border and the interpolation edge detection use as the last step for accuracy improvement. The other interesting criterion for the detection is the time consumption and number of detected parts of the circle.

The cubic interpolation method speed is about 11fps in comparison with canny edge detection which is 15fps. The graph on Fig. 10 shows dependency between detection accuracy and number of measurements. The second graph Fig. 11 shows the same dependency, but the number of measurements is expressed by the size of transformed area. The modified canny edge detector has good results even with relatively small width size of transformed image. The reason is in using of the non-maxima suppression method in combination with threshold hysteresis which provide the extraction of continue edge. These features enable using of the smaller width size of transformed image.

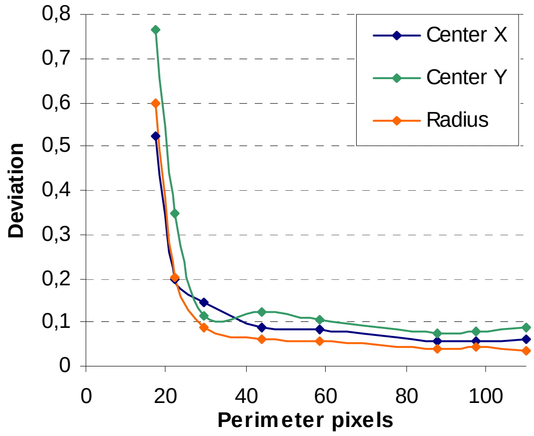

Fig. 10 Accuracy comparison - modified canny detection

The interpolation detection needs more computations for interpolations and higher number of the tested border points which causes smaller speed.

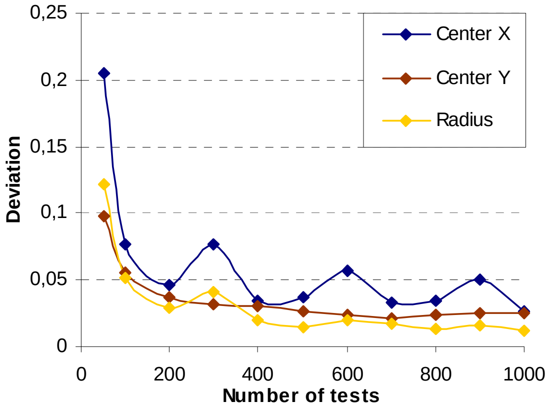

Fig. 11 Accuracy comparison – Interpolation method

The high number of tests in the second graph is also caused by false edge detections which affect the final result.

4. Conclusion

This paper proposes methods for circle parameter estimation from set of border points for omnidirectional image stabilization. Accuracy and behavior of these methods is evaluated and it is choose the best solution for this problem. The edge detection which uses interpolation is prone to false edge detection. The detected edge is computed with sub-pixel precision, but in some cases is detected false edge which decreases precision of the whole result. This method has best results despite this problem. Tests showed that is also suitable as independent method which is able to find the circle in iterative steps. The optimal usage of this method is in combination with the method using modified canny edge detector. Further improvements can be in modification of the non-maxima suppression method to use interpolation of the neighbor pixels. The Kalman filtering can be used for increasing the accuracy and speed of image stabilization.

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