

# A Large Barrel Distortion in an Acquisition System for Multifocal Images Extraction

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**Abstract.** This paper presents a new way to use the well-known distortions introduced by the fisheye lens (ultra-wide-angle lenses) and a well-known algorithms for the correction of distortion in order to obtain completely new functionality in supervision and monitoring of video. The suggested way to use the barrel distortion will result in a smoother zooming and allows to achieve the multiple images simultaneously with the same resolution but with a different viewing angle. This feature may vary greatly increase the effectiveness of surveillance application by providing a greater amount of visual data from one camera.

**Keywords:** barrel distortion, fisheye, surveillance systems, multiresolution

## 1 Introduction

The systems of intelligent image analysis automatize CCTV solutions hence simplifying the operation. Real time image processing in the end device enables identification of emergency conditions by providing security personnel with information required to react and take appropriate action quickly.

Particularly interesting solutions are employed in the area of automatic detection and tracking of moving objects in video sequences. A CCTV system makes a perfect solution if one wants certain areas or premises to be surveilled on regular basis, especially when safety of people is at risk. Classification of the type of incident, detection and identification of people, motion detection as well as image and sound registration imply rapid danger warning. If needed, CCTV system recordings constitute reliable evidence for the police or courts. Modern surveillance systems are not only cameras and video recorders. Currently, two types of solutions are being employed in video surveillance systems: those using rotating cameras (speed dome) equipped with varifocal lenses and those offering megapixel cameras with fixed focal lenses [1,2]. Neither of them is free from drawbacks.

- (i) *A megapixel camera with a fixed focal lens*

This solution is frequently used when recording a wide surveillance field. Several megapixel resolution cameras and high quality fixed focal lenses are used and requires transferring of a very large data stream (with no frame compression). Therefore, a connection of approximately 1 Gbit is needed. If the object tracking is necessary, cropping process may be performed. However, the image obtained after the cropping should be with adequate quality, i.e. it should enable identification or tracking and the image must not be compressed. For cameras offering a resolution of up to several megapixels and even 1 Gbit connection this would signify a low framerate of  $5 \div 15$  frames/sec. This, in turn, has a negative impact on time resolution which is a critical factor for the algorithms of tracking and may cause their faulty operation.

(ii) *A rotating camera with a zoom lens*

Another possibility is to use a recording system with constant low target resolution and varifocal lens. To zoom, in the selected part of the field of vision, the focal length of lens is changed. High resolution of objects under surveillance is thus obtained as well as high time resolution (with a low spatial resolution). Unfortunately, in this case, the surveilled object sometimes is lost from the frame when it is suddenly quickly moving or it disappears when obstacles that block it out are being passed by. Therefore, increasing of the surveilled field requires changing of the focal length of lens. In this type of a system this would mean changing of both the camera position and focal length [3]. While in manual systems it might be a hindrance, in automatic tracking systems such an approach is ruled out.

An attempt has been made to solve the a foresaid problem by combining the advantages of both the approaches and eliminating or attenuating their drawbacks. Another solution might be to use a relatively cost-effective vision system equipped with a camera of moderate, 1-4 megapixel resolution and a fisheye-type fixed focal lens or a fixed focal lens and a mirror (a reflector).

The proposed system enables recording of a wide field of vision and simultaneously offers the possibility of zooming in the image located in the middle of a scene. This solution supports algorithms of object tracking, since, by offering both images with narrow and wide angle of view, the system prevents situations where the object is lost from the recorded image following its rapid movement.

## 2 Optical system

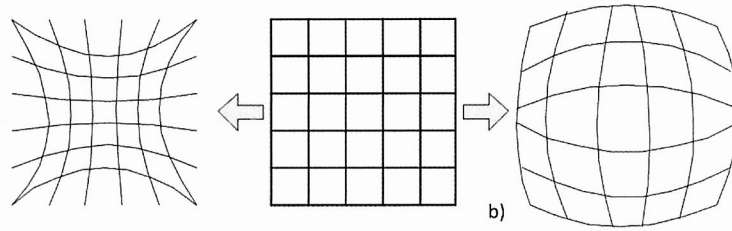
The proposed solution exploits an optical system equipped with a wide-angle lens. Such lenses are characterised by different properties of distortion of the recorded field of vision. In the proposed solution it is possible to use a lens with a large barrel distortion (e.g. fisheye) (Fig.1). To make further analysis, the authors used a 'fisheye' lens. In the case of such lenses, with a large barrel distortion (Fig.2), the reconstructed image is obtained by applying a given mapping function [6], e.g.:



Fig. 1. Original image (left) and 'fisheye' lens-recorded image (right).

- linear mapping (equidistant)  $r = f(k\alpha)$ ,
- stereographic  $r = 2f \tan(\frac{k\alpha}{2})$ ,
- orthographic,  $r = f \sin(k\alpha)$ ,
- equisolid angle  $r = 2f \sin(\frac{k\alpha}{2})$  or other,

where  $k$  is a physical feature of the lens associated with the maximum angle of view. Orthographic or equisolid angle mapping are optimal in terms of use for the proposed solution, as they compress the edges of the frame quite considerably, as a consequence a higher resolution in the centre of the frame is obtained.



**Fig. 2.** Spherical distortion effect.

### 3 Analysis

A lens that does not distort space (all image lines are straight) maps points viewed at an angle  $\alpha$  onto the position of points on the matrix in the way that is described with the below formula:

$$r_0 = f_0 \tan(k_0\alpha) \quad (1)$$

where  $r_0$  is the distance of matrix point from the matrix center and parameters  $k_0$  and focal length  $f_0$  describe the mapping function and the distance of the focus from the matrix and are typical for a given lens. Distance  $f_0$  has an impact on the size of the image that will be produced on the matrix.

For a lens with a considerable compression of frame edges that was selected as the basis for the analyses, the distortion is described with the following formula:

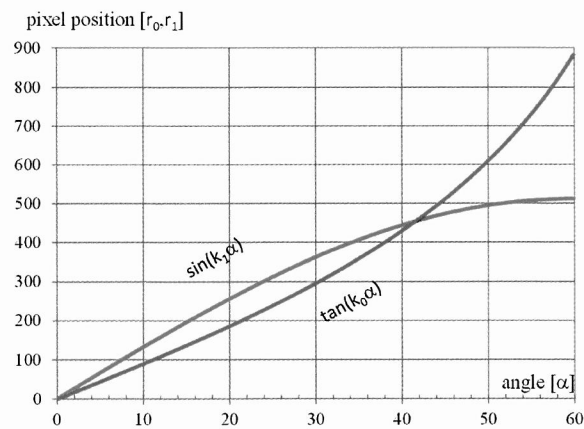
$$r_1 = f_1 \sin(k_1\alpha) \quad (2)$$

The variables have the same meaning as in formula (1). To obtain a correct non-distorted image, an operation of transformation using a function being a compound of functions (1) and (2) is made, assuming that positions of points are searched for a given angle  $\alpha$ . The result is as follows:

$$r_0 = f_0 \tan\left(\frac{k_0}{k_1} \sin^{-1}\left(\frac{r_1}{f_1}\right)\right) \quad (3)$$

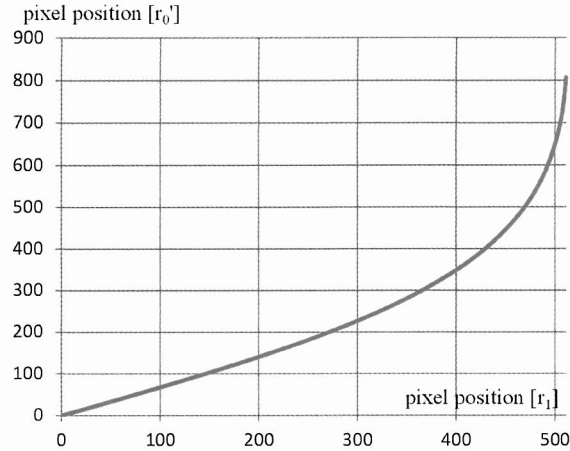
By performing the transformation of an image using the function (1), a correct image with parallel lines is obtained. This image has a different size in points and its resolution decreases when the distance from the image center grows. Two or three images with different angles of view and different resolutions may be obtained from such an image (Fig. 5).

For analytical purposes, acquisition of the image using a fisheye lens with high image edge compression has been assumed. The next assumption is, that algorithm produces 3 images for 3 different angles of view with similar sampling density (Fig. 6).



**Fig. 3.** Functions transforming the surveilled field of vision. In red – a function that does not distort the space; in blue – an example of a function for lenses with considerable frame edge compression.

To obtain an image with the highest zoom, data of zone A will be used (Figs. 5a and 5c). According to the inverse formula a new image is produced by resampling the original image. It has statistically more than one sample per frame pixel in the center of the frame. Whereas at the edge, it is necessary to perform interpolation of the missing samples. In the proposed solution it is sufficient to employ a CCD/CMOS matrix of approximately 1 megapixel together with a distorting lens, e.g. a fisheye. The proposed solution requires a lens with a high compression of image domain at the edges of the frame. A similar approach is made as regards the other two images (Figs. 5b and 5d); with the angles of view growing wider. Also one output image may be produced but with any focal length that will be effective to a certain extent (the result will be similar to a zoom lens). The fragments of a frame responsible for a given angle of view which are compressed are shown in Figure 6. The greater distance from the centre of the frame, the higher the compression, thus the lower the resolution.



**Fig. 4.** Conversion of point positions using an inverse function  $f(x)$ .

We can also generate a single output image with a fixed resolution but also with unrestricted (to some extent) the effective focal length. Then we get a similar effect as in the lens with zoom.

Please note, if the portion of the image is located further from the center of the frame, the greater compression of samples and a lower of the output resolution. This results in some loss of resolution is reflected in a blur at the corners of the image.

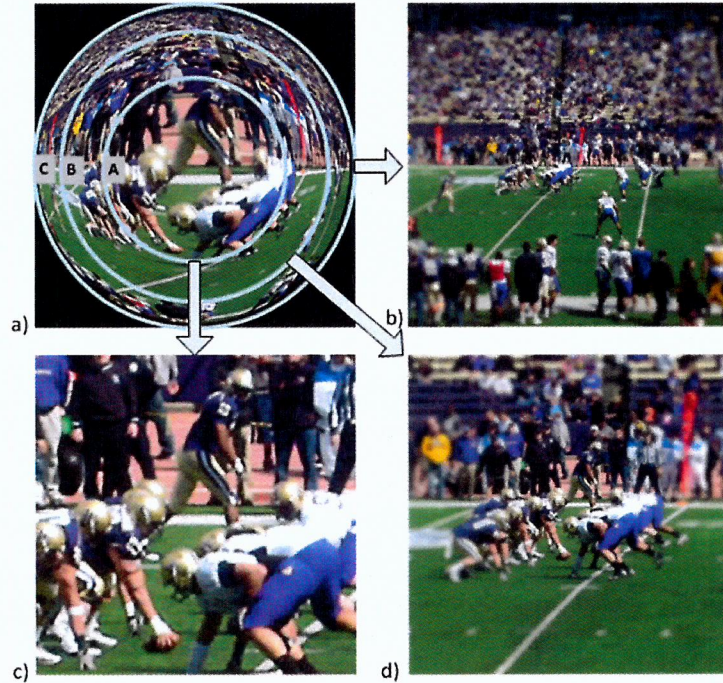
## 4 Conclusions

This paper presents the idea of employing a barrel distortion to obtain an effect similar to focal length modification in vision systems equipped with fixed focal lenses. It requires applying a dedicated mapping function. A general computational complexity of such mapping function is very low [4,5].

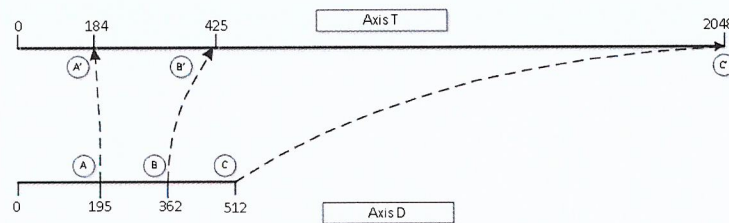
For instance, if 1 megapixel matrix (512 x 512 pixels) and a lens with a large barrel distortion is used, an image may be obtained with the angle of view of  $160^\circ$  and a segment from the centre of matrix (zoom) with the angle of  $40^\circ$  and resolution (184 x 184 pixels).

According to Figure 6, three images may be obtained with different angles of view and resolution. However, to obtain the same resolution of an image segment (in this case 184 x 184 pixels) from a lens without distortion with the same total angle of view ( $160^\circ$ ), one would have to use a matrix whose resolution would be approximately 16 times greater, i.e. 16 megapixels. This also means that a framerate as high as the one offered by 1 megapixel matrix would not be obtained. High framerate is an advantage in the case of algorithms of automatic detection or object tracking.





**Fig. 5.** An example of obtaining of 3 images with similar resolution and different angle of scene capturing (effectively different focal length)



**Fig. 6.** Correction of a distortion for an example of a fisheye lens. Axis D mapping with distortion (one line from point (0,0) to (0, 511) onto the T axis (one line from point (0,0) to (0, 2047)). Points: (A) – angle of view  $40^\circ$ , (B) – angle of view  $80^\circ$  and (C) – angle of view  $160^\circ$ .

Therefore, the proposed solution may be used to construct a system that would enable fluent modifications of the focal length with a fixed focal lens ('fisheye'). Nevertheless, application of the presented solution in the systems of automatic tracking and identification of objects seems to be far more interesting. The presented approach allows obtaining simultaneously several images with different angles of view and similar resolution based on one source image. As a result of that, it is possible to analyse and track an object in several image planes at the same time which efficiently prevents losing of the object that is being tracked. Escape an object from the frame with the greatest zoom does not result in the break of the object track, because the object may be tracked in planes with greater angle of view simultaneously (smaller zoom).

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