Fast Correction of Lens Distortion for Image Applications

J. C. Aparicio Fernandes

Department of Industrial Electronics
University of Minho
4800 Guimarães, Portugal
Email: Aparicio.Fernandes@dei.uminho.pt

Manuel João O. Ferreira

Manufacturing System Engineering Unit
INESC - Porto
4000 Porto, Portugal
Email: mjf@inescn.pt

José Alberto B. Campos Neves

DEI
Lusíada University
4760 Vila Nova de Famalicão, Portugal
Email: cneves@fam.ulusiada.pt

Carlos A. C. Couto

Department of Industrial Electronics
University of Minho
4800 Guimarães, Portugal
Email: Carlos.Couto@dei.uminho.pt

***Abstract* - The main use of video cameras in industrial applications regards to detection of defects and non-contact measuring. If the first case is usually a problem of mismatching between two images, the absolute position being non-important, the second relies on accurate proportional correspondence between image and object dimensions.**

In the usual set-up, the object is mainly flat and its image is obtained using a video camera whose lens axis is orthogonal and centred relative to the object. The co-ordinate system of the object should be ideally related to that of the image by a simple translation and change of scale, once an initial mechanical rotation adjustment of the set-up is made.

The geometric distortions, mainly pincushion and barrel types, must be either avoided, using a well-corrected lens in a proper set-up, or corrected through digital image processing techniques. The use of an acceptable lens imposes a higher price or restrictions to the angle of view, as wide angles are harder to correct acceptably. When space limitations are important and a wide angle is sought, an expensive lens and/or time consuming correcting algorithms are mandatory.

The proposed algorithm builds a correction table for the set-up in use, which remains fairly constant in industrial applications. This table divides the image in regions. For each region the correction can be put as a single delta-x/delta-y translation of the included pixels. This can be done fairly quickly when compared to the general morphing algorithms.

I. INTRODUCTION

The use of a video camera to get an image of an object, to be converted to a digital format and further processed by digital algorithms is usual in industry. There are lots of industrial equipment recurring to these techniques and their use is increasing [1,2,3].

The optical image formation process recurs to lenses, whose ability to form an image on the surface of a sensor is known for a long time [1,2,3,4]. Nevertheless, this process is prone to some well-known errors that limit the quality of the image and, if not taken into account, may limit the validity of the derived results [1,2,3,4].

The residual distortion remaining in the optical system depends upon the restraints imposed to the calculation of the complex lens. The practicable lenses are made of several simple components, whose association allows concealment or, at least, minimisation of the image formation errors simple lenses have [5]. The final quality of the optical system is a balance between complexity of design, manufacturing tolerances, relative importance of lens characteristics and price [5]. Some residual image formation errors are unavoidable in the assembled lens. Those errors - or distortions - are usually classified and measured according to the effect on the produced images. Barrel and Pincushion are two of those problems. The names derive from the shape that the image of a rectangle takes: the central dimensions are reduced (pincushion) or enlarged (barrel) in relation to the sides (Fig.1).

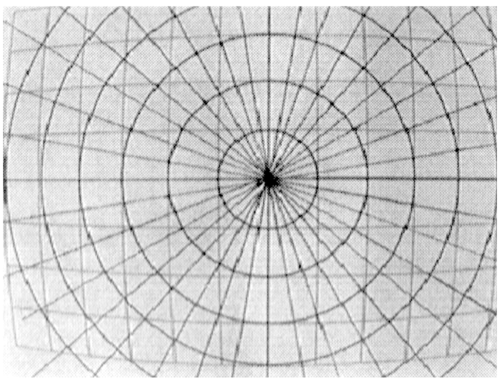

Fig.1 Geometric pattern used for calculation of distortion correction factors - Barrel distortion

If this kind of image is used to obtain dimensional data for the object, the errors are self-evident: the dimensions of the rectangle taken from the distances between consecutive vertices are different from those taken from the centres of the 'sides' of the rectangles. For the most common irregular shapes, without straight borders, the distortions are not apparent, and can be easily overlooked.

The correction of this kind of distortions is more difficult when the angle of view increases. Wide-angle lenses are noticeable for their residual pincushion/barrel errors, that are normally much larger than those for normal lenses. When the available distance to capture the image is short and precludes the use of a normal lens to capture the whole object, the use of a wide-angle lens is the only solution.

This work was undertaken to compensate for distortions in images used in a CAD/CAM computer vision system developed for shoe industry, at INESC. Part of the results are already in use in several factories [6].

II. USUAL ALGORITHM FOR IMAGE DISTORTIONS CORRECTION

The correction can be made using a stretching transformation [1,4,7]. The system is tested with a rectangular grid as object (Fig.1). The barrel distortion is self-evident. The co-ordinates of the crossing points are extracted in the resulting image, and the correct locations are ascertained, taking the central dimensions (where distortion effects are minimal) as reference. The 'real' grid is taken as distortion of the ideal: the corrected pixels are calculated by bilinear interpolation, taking as extremes the vertices of the defined regular grid. This is to be done for every pixel and the choice of grid cell size is a trade-off between complexity (many cells) and quality of the results (the errors introduced by using a linear interpolation to correct for an essentially non-liner process inside a big cell are larger than for a smaller cell) [6,7].

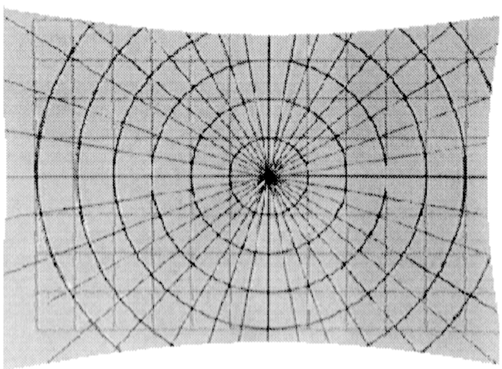

Fig.2 Corrected image

This approach also needs computations to be made for every image. It is not possible to make the calculations for a test image and just use the results for every other image. The only parts we use are the co-ordinates of the grid vertices, both in the corrected and in the uncorrected images. The result is shown in Fig.2.

III. THE PROPOSED APPROACH

In order to speed the process for several images obtained in the same set-up, the calculations should be made once and the results stored in such a way to be used without need of lengthy recalculations.

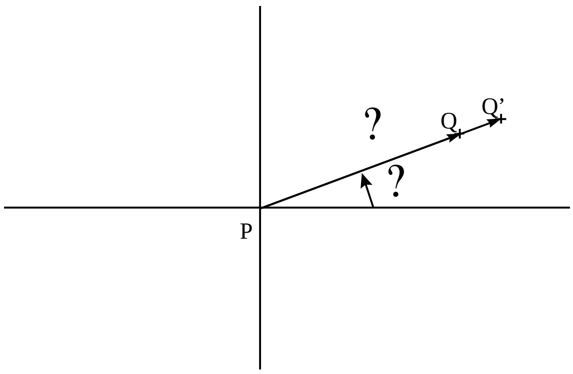

Fig.3 Barrel distortion and polar co-ordinates

The barrel/pincushion distortions present in a certain lens depend on the conjugate object-image distances used, and also on the angle of view of the particular point in reference to the optical axis of the lens. The technology of lens manufacturing uses spherical surfaces, and the mounting of the lens elements to build the complex set is a well-known and quite well controlled process. Therefore, we should not expect to have different kinds of distortion for equivalent points. That is, if we use a polar co-ordinate system for the object and image planes, using as central point the crossing of those planes with the optical axis of the lens (Fig 3), the distortion should be insensitive to variations in ?, and could be put in function only of ?.

Due also to the digital form of the image, the discretization process could be put to our advantage: we should need only to change the placement of the original picture elements to the nearest correct location. Differences up to a half pixel could be disregarded. Also due to the smooth distortion effect, the translation of neighbouring pixels would be equivalent, and we can define regions where pixels can be shifted by the same amount. The symmetries present indicate that a half a quadrant would be need for the translation calculations.

IV. EXPERIMENTAL RESULTS

We started using a 6 mm grand angular lens mounted on a ½” CCD video camera connected to an inexpensive digitising board in a PC.

The first problem was to determine the central point P on the image, to use as origin of the polar co-ordinate system. Several experimental techniques were devised, but the simplest gave so good results that we tried no further: we needed only to look for the point where straight lines do not present any discernible bending. The distortion, being only radial, does not change the shape of a straight line through the origin, and such lines are also straight in the real image (Fig 4) [6].

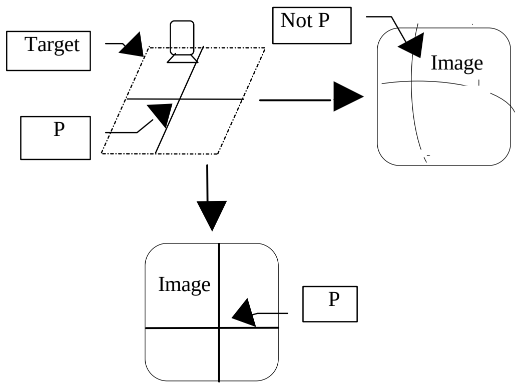

Fig. 4 Central Point P on the Image.

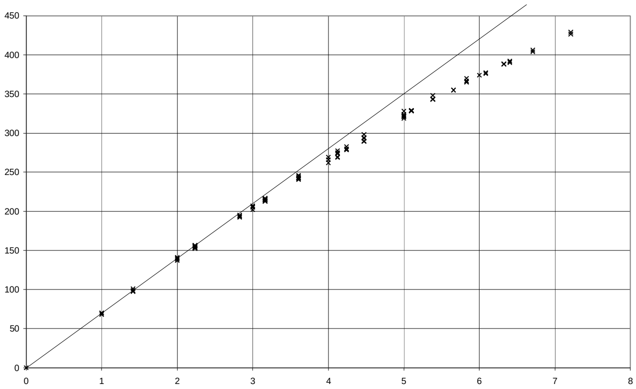

Fig 5 Graphical display of Barrel Distortion

This point is not centred in the digital image. The main reasons are a slight shift of the CCD sensor in regard to the mechanical fixture of the lens and also some possibility of adjustments of the useful video image in the monitor screen, allowing some cropping.

For the image of Fig.1 several adjustments to the test target position were needed, until the central

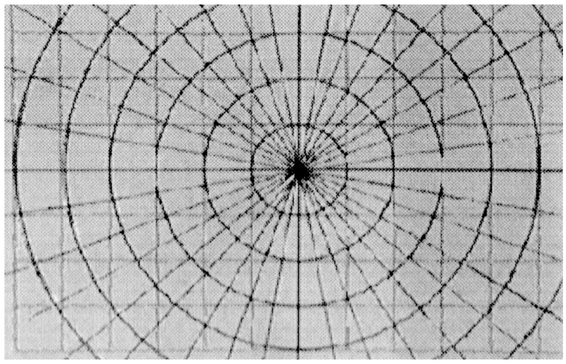

Fig. 6 The corrected image from Fig. 1,using the proposed method

point and orientation of vertical and horizontal lines were as intended.

We measured the co-ordinates of the crossing grid points in terms of pixel co-ordinates. After calculating the equivalent distances to the central P point, the plot of Fig.5 was obtained. The yy’ axis represents the distances in image co-ordinates and the xx’ axis the object distances taking as unity the grid size. The marked points are experimental data. The line corresponds to the fitting of a straight line for distances up 2 grid units, where the fitting was perfect. The experiment also showed a perfect match between horizontal and vertical co-ordinates, indicating the good squareness of the pixels.

Although the final details are still under testing, the process is as follows:

a) We used a polynomial fitting of the data, and put the results as a look-up table.
b) We store the translation data as a pair of integers for each pixel in an image whose size is larger than a quarter of the original one; in our case we needed 428x280, the biggest rectangle we could define using each corners of the image and the optical central point P.
c) for each pixel Q(x,y) we compute the distance to the origin - sqr(x2+y2) - that is used as entry to the lookup table
d) the output that corresponds to the distance to the origin in the uncorrected image is divided by the distance in c), producing floating-point number.
e) this number is used as a factor to multiply the co-ordinates (x,y), producing, by rounding, two integers that we store in the address (x,y) of the matrix defined in b)
f) We use this procedure for all possible pairs (x,y)

With this process concluded we are able to correct any image taken with the same set-up. The process works as follows:

a) for each possible pixel co-ordinate pair we orderly subtract the co-ordinates of the central point, keeping the signals of the results

b) taking the absolute values, we use them as the address in the matrix for the integer pair that carries the relative co-ordinates of the original pixel
c) these values are translated in absolute co-ordinates, adding the co-ordinates of the central point to the values obtained in b), signal corrected according to a)
d) we look in the original image for the value of that pixel, which is stored in the corrected image address.

The algorithm applied to the image in Fig.1 produced the results in Fig.6. Differences from Fig. 2 are minimal. The apparent scale factor difference results from the intended use of the original image size (320x240 pixels) and respecting the scaling in the central image.

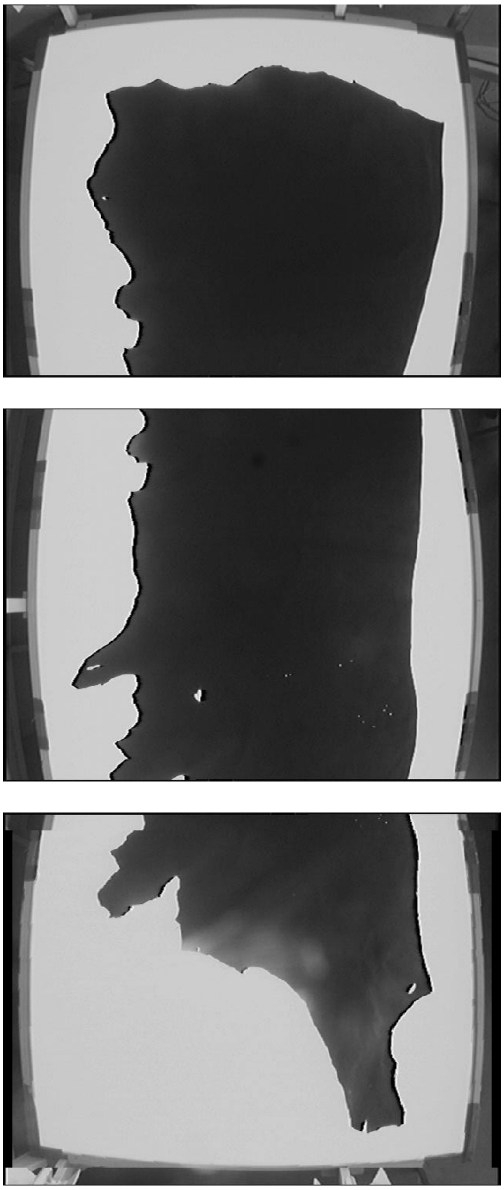

Fig. 7 Original images to combine to form a single image

The use of this technique for the computer vision system developed for the shoe industry [6] envisaged a lower processing time. There are three images to process, obtained from three different video cameras to be combined in a single image (Figs. 7 and 8). The time saved in each correction is tripled.

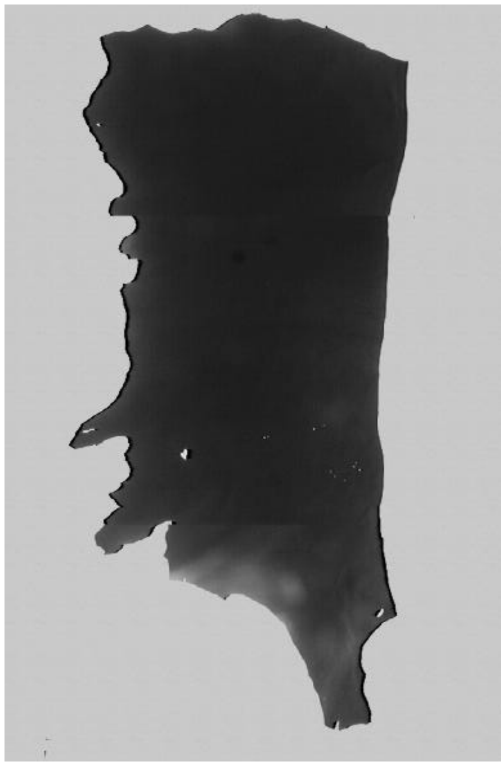

Fig. 8 The image resulting from combination of images in Fig.7

V. CONCLUSIONS

The application of this method produced images almost identical to the ones obtained by the traditional method (Figs. 2 and 6).

Although the initial computations took almost as long as the previous method, the corrections of any subsequent image were much faster.

Our need of three corrections for each final image meant large savings in processing time.

At this moment we are unable to quantify the speed up as we have just upgraded the system for a faster processor and more memory.

The reduced size of the matrix with the computed results, originally justified by the limited memory resources we had in the computer is no-longer restraining

We also plan to simplify and speed up the process, using matrices with dimensions corresponding to the full image, avoiding the burden of relative co-ordinate calculations.

The use of three camera/lens combinations, that we thought to imply the use of a different calibration matrix were solved using a single correction scheme. The use of identical cameras, lenses and working distances produced equal values for both the centre location and distortion characteristics (Figs. 4 and 5).

VI. REFERENCES

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