IMAGE DISTORTION FROM ZOOM LENSES : MODELING AND DIGITAL CORRECTION

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INTRODUCTION

Television camera lenses and in particular variable focal lenses (zoom lenses) are not perfect optical instruments. they provide images with two kinds of optical defects [BURC67], [CHRE80]: geometric and chromatic aberration. The first usually presents itself in one of five ways: spherical aberration, coma, astigmatism, field curvature and distortion. For the second, we distinguish two kinds of aberration: lateral chromatic aberration and longitudinal chromatic aberration.

As seen from the camera, the defects are those which deform the image, i.e. are geometric distortion and longitudinal and lateral chromatic aberration. Under the effect of geometric distortion, a squared grid will become a curvilinear grid (fig.1).

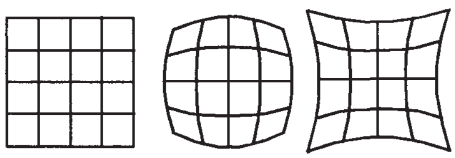


Fig.1. Barrel and pincushion distortion.

Lateral chromatic aberration is characterised by a lateral spacing out of the diverse radiations which lead a lightly spread spectrum displayed on the screen (fig.2). This phenomenon is due to the dispersion of the different incident radiations through the lens.

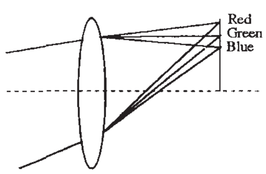


Fig.2. Lateral chromatic aberration

For tube cameras, these distortion defects and the lateral chromatic aberration within the tube scan are corrected. In the case of CCD based systems, of concern to us today, this correction principle is no longer applicable. Even if the defects are negligeable in current TV standards, they become important in HDTV and very high resolution image analysis. Thus, the purpose of this paper is to propose a method of digital correction of distortion and lateral chromatic aberration effects before image processing and viewing.

Digital correction is applied in two steps. The first step consists of a geometric transformation applied to the distorted digital image [PRAT91]. This transformation is defined from a mathematical model of the defects. The second step gives, from the transformed points, the estimation of the final digital image points. This estimation is carried out by local linear interpolation [AKIM78], [BIZA82], [MULD82].

In order to determine the applied geometric transformation, we have studied two methods. The first is a global correction method. The second is specific to our application.

POLYNOMIAL WARPING CORRECTION METHOD

This is the most commonly used method to correct image deformations [CHRI88], [STEV89]. It requires, on one hand, knowledge of the reference points or "control points" and, on the other hand, the use of a polynomial fitting criteria that is usualy "least-squares". The control points are a set of points belonging to the distorted image and for which we know the correspondence to the ideal image. The performance of this method depends on the precision with which the control points are determined.

Principle

From the set of control points we determine a polynomial equation of degree N. The polynomial equation coefficients are computed from these points by least-squares minimization. When the model parameters are determined, we apply the transformation to all the distorted image points to obtain the corrected image.

Determination of the control points

The control points form a set which contain points belonging to the distorted image and their correspondent points in the ideal image. The choice of points in the image is left to the human operator. This operator decides on the distribution of the points taking into account the visible distortion of the image.
In order to determine these points, several approaches have been proposed ([ARDE86], [CHRI88],[DIJA85]), and usually require the registration of the grid appropriate to the image with a generated grid representing the same structure.

Our choice has been to use tables of experimental values characterizing the distortion, which are provided by the various lens manufacturers. These tables provide the percentage of distortion as a function of the zoom parameters (subject distance, variation of focal length, ...) The control point coordinates are computed from these values.

Determination of the polynomial function

Given a set of distorted image control points (x_{dk}, y_{dk}) and given their correspondences in the ideal image (x_k,y_k) a polynomial function relating the two sets of points is given by (1). With k = [1,z], where z is the number of control points used.

$$x_k = \sum_{i=0}^{N} \sum_{j=0}^{N} K_{ij} \cdot x_{dk}^{i} \cdot y_{dk}^{j}$$
$$y_k = \sum_{i=0}^{N} \sum_{j=0}^{N} L_{ij} \cdot x_{dk}^{i} \cdot y_{dk}^{j} \qquad (1)$$

For z control points we then obtain a system of equations equivalent to (2). The coefficients K_{ij} and L_{ij} are computed by minimizing *the least-squares fit criteria,* which has a general solution gived by (3):

$$M(z,n) \cdot K(n) = X[z]$$
$$M(z,n) \cdot L(n) = Y[z] \qquad (2)$$

n = number of coefficients.
M(z,n) = z x n matrix.
K(n) = vector of x polynomial coefficients.
L(n) = vector of y polynomial coefficients.

$$K(n) = [M^T(n,z) \cdot M(z,n)]^{-1} \cdot M^T(z,n) X[z]$$
$$L(n) = [M^T(n,z) \cdot M(z,n)]^{-1} \cdot M^T(z,n) Y[z] \qquad (3)$$

Once the coefficients K_{ij} et L_{ij} are obtained, we apply the transformation to all the distorted image points. From that we obtain a set of points which characterizes the correct image.

PROPOSED METHOD

In our applications, it is the geometric distortion which is of interest. The principal characteristic of the deformations is that they are symmetrical about the center of the captured image.

The correction method that we propose takes into account this property.

The principle is to define in the first instance a characteristic distortion function. For that an interpolation using splines based on the given experimental data is computed. Next we apply a correction (depending of the previously obtained function) to all the points of one of the four image quadrants. The other points are obtained by symmetry. The principle by which the characteristic function is determined is illustrated in the following (fig.3).

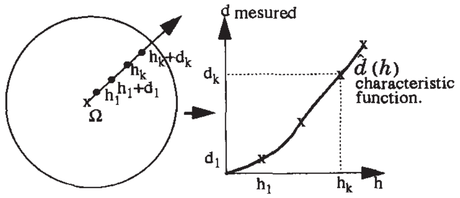


Fig.3: Stage in the determination of the characteristic function.

Distortion charateristic function

In order to remain sensitive to local variations in distortion, spline functions was chosen to characterise the distortion. These was calculated, for a given focal length, a given subject distance ..., as a function of image height and therefore as a function of the position of the point relative to the image center.

The equation of the cubic spline at the interval i is given by (4) [FOLE84]:

$$\hat{d}(h) = a_i (h - h_i)^3 + b_i (h - h_i)^2 + c_i (h - h_i) + g_i \qquad (4)$$

Where:

$\hat{d}(h)$ = distortion
h = distance from the image center
should $p_i = h_{i+1} - h_i$ and where q is the second derivative, we get:

$a_i = (q_{i+1} - q_i) / 6p_i$
$b_i = q_i / 2$
$c_i = (d_{i+1} - d_i) / p_i - h_{i+1}(2x\, q_i + q_{i+1}) / 6$
$g_i = d_i$.

The expression (4) allows us to estimate the value of the distortion for each image height, from which we can determine the correct point coordinates.

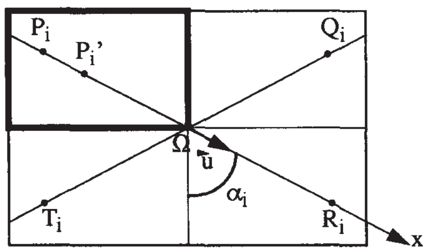
Correction of the image points

For each point P_i of a distorted image quadrant we can determine:

The distance P_i in terms of Ω: h_i

$$h_i = \left\| \overrightarrow{\Omega P_i} \right\|$$

The angle a_i.



Then we can determine the position of the correct point P_i':

$$\overrightarrow{\Omega P'_i} = \overrightarrow{\Omega P_i} + \hat{d}(h_i) \times \vec{u}$$

The coordinates of P_i' determined by the following equations:

$$x_{P'_i} = x_{P_i} + \hat{d}(h_i) \cos \alpha_i$$

$$y_{P'_i} = y_{P_i} + \hat{d}(h_i) \sin \alpha_i$$

Q_i, R_i and T_i are symmetric:

$$x_{Q'_i} = x_{Q_i} + \hat{d}(h_i) \cos \alpha_i$$

$$y_{Q'_i} = y_{Q_i} - \hat{d}(h_i) \sin \alpha_i$$

$$x_{T'_i} = x_{T_i} - \hat{d}(h_i) \cos \alpha_i$$

$$y_{T'_i} = y_{T_i} + \hat{d}(h_i) \sin \alpha_i$$

$$x_{R'_i} = x_{R_i} - \hat{d}(h_i) \cos \alpha_i$$

$$y_{R'_i} = y_{R_i} - \hat{d}(h_i) \sin \alpha_i$$

RESULTS AND CONCLUSIONS.

We have tested the two methods presented in this paper. Taking the general method by polynomial transformation, the best performances (on an image of 576x720 points with 150 control points) in terms of level of precision of the correction were obtained for a 3^{rd} level polynomial. In the same conditions, the proposed method gives an equivalent precision. However the proposed method gives a greatly improved processing time. In practice, trials performed on the same machine (Sun 4/470) gave results in the order of 27s for the general method against 8s for the proposed method.

For the application of interest to us (correction of geometric distortion in zoom lenses) the transformation method is interesting but costly in calculation terms. This method allows for the correction of distortions whose sources are not known and is therefore very general for our specific case of deformation.

On the other hand, since our method takes into account the origin of the deformations, the algorithm is simpler. The advantage which is gained is the possibility of real time correction with a hard-wired solution.

This system can be used for correction of zoom lens on broadcast cameras. It is particularly useful for HDTV equipment where quality must be at the highest level.

The first application developped at Thomson Broadcast is a very high definition scanner (6000 pixels x 8000 lines) where distortion and chromatic aberrations have been corrected.

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