Information Sciences 366 (2016) 70–98

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Automatic correction of barrel distorted images using a cascaded evolutionary estimator

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ARTICLE INFO

Article history:
Received 5 December 2015
Revised 21 February 2016
Accepted 26 March 2016
Available online 24 May 2016

Keywords:
Distortion correction
Biometrics
Evolutionary algorithms
Cascaded estimators

ABSTRACT

All optical systems are to some extent burdened by one or more aberrations. Barrel distortion of an image is also an aberration. In this paper we used an innovative method to solve the problem of the centric radial distortion of a static image which serves for biometric identification of persons using 2D contour of a human hand. The method proposed uses a cascaded arrangement of two algorithms – the classic meta-heuristic, referred to as “jDE-differential evolution” and an algorithm called Covariance Matrix Adaptation Evolution Strategy. Optimizers use methods of inverse engineering and numerical mathematics to resolve the question of how to determine the correct parameters of the algebraic polynomial equation of the nth degree, by the application of which it is possible to obtain an image free of barrel distortion from an image affected by this distortion. The proposed method provides a high-quality and time-acceptable method of optimization and the option of choosing the approximation accuracy. With the use of the coefficients obtained, it is then possible to use a method called back-mapping to permanently correct the centric radial distortion aberration in the biometric scanner. Extensive experiments presented in this paper enable a better understanding of relationships, the accuracy obtained, and options of using evolutionary optimizers in a larger sense.

1. Introduction

Working with optical systems; i.e., lenses or mirrors, we may come across many optical aberrations [101,130]. Five well known deficiencies of projection or aberrations were first described earlier in 1857 by the German mathematician Ludwig von Seidel with monochromatic light. These are the following defects: spherical aberration, coma, astigmatism, curvature of field and distortion. Very often one more aberration is added to those mentioned above; the chromatic aberration (color defect). For most commonly available commercial optical systems which are used e.g. in cameras or film/video recorders, all optical aberrations mentioned above are compensated to some extent by the manufacturer when the optical system is designed. Some of them, such as distortion [15], can be markedly exerted at the moment when the optical system must display an image which is, for example, obtained with a lens with a large field of view (FOV - Field Of View) and small input pupilla [45]. Typical representatives are lenses referred to as “fish-eye lenses” [8,103]. Perfect correction of all aberrations under all circumstances is not feasible due to physical laws. For specific purposes, various types of optical systems are used – e.g. exchangeable camera lenses. In the area of digital image processing, such as for cameras or recorders, it is necessary that the optical aberrations which were not corrected by the system of lenses or mirrors be corrected in another suitable way.

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http://dx.doi.org/10.1016/j.ins.2016.03.055
0020-0255/

These days it is usual that an image from a camera is processed using software with a computer. Digital image processing is time demanding due to the huge volume of input data which for digital corrections of aberrations also represents a huge volume of output data. This applies for example to image distortion correction for a biometric scanner, which is our case. In this paper, information from the three different areas is used:

(1) Optical systems aberration correction [35,101,126], namely barrel distortion correction of an image [17]; polynomial method.
(2) Selected modern evolutionary algorithms [39] which are used here as standard optimization instruments of two and seven lens function.
(3) And also some findings on cascaded estimators [87].

The proposed algorithm which enables the removal of undesirable aberrations of the image in this way, in our case barrel or pillow aberration of a small range, is referred to as a Cascaded Evolutionary Estimator (CEE). The first part of the paper is devoted to a general survey of literature in the area of barrel distortion correction, here the evolutionary estimators used are also described in detail; this is followed by a short paragraph devoted to the topic of cascaded estimators and also by a paragraph devoted to the theoretical analysis of possibilities in barrel distortion correction and commonly used methods. The next chapter describes CEE. The conclusion of the paper is devoted to a selection of suitable working parameters and, of course, to experimental results which describe the behavior of the proposed CEE under various working conditions.

2. Related work

A method of correcting image distortion - both centring and decentring - has already been proposed by Conrady [22]. [19] using the findings in [72] derived and experimentally verified a formula which accounts for the variation of distortion with changing focus. Well known are also articles [15] and especially [17]. At the time of the personal computer invasion at the end of the 80s, Brown's research came into use primarily in military forces and in industry and later in astronomy, aeronautics and many other branches, and in an unchanged form is still utilized today. Articles [15,17] became to some extent referential in the given scientific area. The method of centric distortion correction is not always suitable in the harshest military conditions; hence several other articles were published [16–18], where, among other things, a method for correcting decentring image distortion was proposed.

Methods proposed in scientific literature to remove image distortion may be divided into various categories according to such things as the type of calibration image or for which type of lens the method is proposed, etc. Let us sum up some of the most well-known articles and sort them into categories according to their usage: e.g. medicine [2,3,45,58,74,75,88,104,36] or the area of machine vision [136,68], military photogrammetry and aeronautics [17,117,118], surveillance [66], robotics [20,34], and industry [116,121,114]. A complete survey of the methods mentioned above, which deal with radial centring/decentring lens distortion correction, was introduced by Fryer [38] who also took into account scientific advances in this field and new technological possibilities. A historical survey can be found in [68,21]. Other, newer survey studies from the field of close-range photogrammetry and computer vision were introduced in [73,98] and the publication by Slama [106] is also interesting in this respect.

Correction distortion methods are usually based on a calibration pattern that is composed either of points [3,102,121,28,29], lines/grid [92,118,120,122,136,26,34] or with other composite patterns [99,129,128]. The method may also be based on seeking suitable features in an image [14]. [92] demonstrated that the methods which use points or lines as their calibration pattern provide identical results from the accuracy point of view.

So called classic polynomial methods, or methods based on a polynomial radial model (PM) [17], are represented in articles such as [131,3]. There is not only one way to describe image distortion. There are other methods such as non-polynomial methods [66] which are characterized primarily by their speed. Dhane et al. [30] proposed a so-called non-polynomial non-linear radial stretching method. Basu, and Licardie [8] proposed a logarithmic distortion model called Fish-Eye Transform (FET) and also Polynomial Fish-eye Transform (PFET) and on the basis of experiments, concluded that PFET works better than the FET model. Fitzgibbon [36] proposed modifying the polynomial model [17] and identified it as a 'division model' (DM). Its advantage is that this model is capable of removing a large distortion better than the traditional model (PM). A simplified DM is also used in [128]. A comparative study of the efficiency of the polynomial model (PM) - odd order, PFET, and DM for fish-eye lens is presented in [57].

The necessity of correcting image distortion arises under certain circumstances in almost all optical systems. An independent chapter is that formed by "fish-eye" lenses which are able to display a large field of view $\sim 180^\circ$ and which are very popular in the area of image processing. There were many methods proposed to remove distortion for these types of lenses, such as [102,30] etc. The methods can be either fully automatic, namely self/auto calibrating [129,14] or based on purely iterative "hand-made" parameter estimation [45,24,26]. For common commercial cameras with good quality lenses – compact cameras – for which distortion regarding focal distance is not so large, it is possible to use the method proposed in [26]. A group of researchers [3] proposed an iterative algorithm which originates in earlier investigations [110,45] and resolves the problem of barrel distortion in endoscopes. They assume that the centre of distortion is placed into the centre of the image. The problem of 2D distortion is thought to be purely non-linear. [3] transform the 2D problem of non-linear transformation of the image to a 1D problem using an iterative method.