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Research Paper

Leaf classification from binary image via artificial intelligence

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The invariant recognition of 2D binary images is the main subject of the paper. Two methods for invariant pattern recognition based on 2D Fourier power spectrum with guaranteed translation invariance are proposed. First method introduce the features invariant to translation, scaling, rotation and mirroring (TSO invariance). The second method introduces the features invariant to general affine transform (A invariance). The methods are used to obtain TSO/A invariant spectra except of the rotation effect which are analysed on circular paths with fixed radii. Harmonic analysis of power fluctuations around paths generates Fourier coefficients and their square absolute values are used as TSO/A invariant descriptors. The proposed methods were tested on two large sets of 2D digital images of tree leaves. After TSO/A invariant processing of thresholded digital images, kernel Support Vector Machine or self-organizing neural network were used for leaf categorisation.

1. Introduction

Because the extraction of invariant features plays an important role in many fields of computer vision, invariant recognition of 2D images is problem which is currently being investigated by many researchers. Generally, the methods for obtaining of feature description can be divided into methods processing the whole 2D image and those processing only the contour. The use of morphological characters such as aspect ratio, rectangularity, convex area ratio, convex perimeter ratio, sphericity, circularity, eccentricity, and form factor can be insufficient in case of an object with holes, because objects with the same characters can be easily found. The same problems can occur in the case of processing the contour of image only, because objects with holes have multiple contours, which underlie the same deformation, but obtaining the invariant description is difficult. Among these methods Fourier descriptors (Cosgriff, 1960) dominate and there exist several methods for their normalisation with respect to translation, scaling, rotational changes (Gonzalez & Woods, 2008; Zhang & Lu, 2003) and methods for normalisation with respect to affine transform (Arbter, 1989; Zhang & Lu, 2003). Yang, Lan, Tang, & Chen (2012) converted an object into a closed curve called a radial centroid curve. The affine invariant function is constructed by applying a stationary wavelet transform to the derived curve. Yang, Chen, & Scalia (2012) constructed the affine invariant functions directly in spatial domain, on the object contour without any

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Nomenclature

Abbreviations

A invariance	Invariance to general affine transform
AIA	Absolute distance from ideal alternative criterion
CENTRIST	Census transform histogram
DP	Dynamic programming
HARS	Harmonic analysis of radialized spectrum
HATSIS	Harmonic analysis of TS invariant spectrum
HATSI&RS	Combination of HARS and HATSIS system
IDSC	Inner-distance shape context
LIBSVM	Library for support vector machines
MAP	Mean average precision
MDS	Multi-dimensional scaling
PACT	Principal component analysis of census transform histograms
PCA	Principal component analysis
SC	Shape context
SOM	Self-organised mapping
sPACT	Spatial PACT
SPTC	Shortest path texture context
SVM	Support vector machine
TS	Translation and scaling
TSL	Triangle side lengths
TSLA	Triangle side lengths and angle
TSO invariance	Invariance to translation, scaling, rotation and mirroring
1-NN	1-nearest neighbour

List of symbols

f	2D image function
f^+	Discrete 2D image function
$F(\omega_1, \omega_2)$	Continuous 2D Fourier transform
$F^+(\omega_1, \omega_2)$	Discrete 2D Fourier transform
$L(\omega)$	Lower envelope
$L^+(\omega)$	Lower envelope of discrete spectrum
ω^*	Reference point for $L(\omega)$
ω^{*+}	Reference point for $L^+(\omega)$
$m_{p,q}$	Image moments
$m^+_{p,q}$	Discrete image moments
$\mu_{p,q}$	Modified central image moments
$\mu^+_{p,q}$	Modified discrete central image moments
$\Upsilon(\omega_1, \omega_2)$	Translation and scaling invariant spectrum
$\Upsilon^+(\omega_1, \omega_2)$	Discrete translation and scaling invariant spectrum
$\Phi(\omega_1, \omega_2)$	Normalised 2D power spectrum
$\Phi^+(\omega_1, \omega_2)$	Discrete normalised 2D power spectrum
$\Psi(\omega_1, \omega_2)$	Radially symmetric 2D spectrum
$\Psi^+(\omega_1, \omega_2)$	Discrete radially symmetric 2D spectrum
$C_n(\omega)$	Harmonics of spectrum Ψ
$C^+_n(\omega)$	Harmonics of spectrum Ψ^+
$T_n(\omega)$	Harmonics of spectrum Υ
$T^+_n(\omega)$	Harmonics of spectrum Υ^+
se_k	Sensitivity for the kth class

transformation. They also introduced cutting affine moment invariants (Yang, Li, Chen, & Chen, 2012). The original image is cut into two areas by a closed curve called general contour. Then the traditional affine moment invariants method is applied to the new image, which is obtained by changing grey value of pixels in the inside area. Sheta, Baareh, and Al-Batah (2012) proposed the fuzzy system for 3D objects recognition based on 2D images. They used the fuzzy mathematical model of the extracted features for the classification. Ho and Yang (2011) introduced a method for affine registration of 2D point sets using complex numbers. It is based on polynomials with complex coefficients whose roots are the points in a given point set. Universal methods for shape-based description are based on the whole binary image, where holes do not cause difficulties. Hu (1962) proposed moments invariants for translation, scaling, and rotation. They are useful tools for asymmetric objects, because certain moments have zero values for symmetric ones. Flusser and Suk (1993) introduced the moment invariants, which are invariant against general affine transformation and may be used for recognition of affine-deformed objects. Later Suk and Flusser (2011) published a general method of systematic derivation of affine moment invariants of any weights and orders, whereas each invariant is expressed by its generating graph.

This paper presents two novel methods for constructing of the descriptors invariant to translation, scaling, and transform with orthonormal matrix (rotation and mirroring), and consequently the affine invariant descriptors both based on 2D Fourier transform. The methods consist of three steps. Firstly, with both methods the original image is converted to its power spectrum. Then in the first method, a reference point is used to obtain the translation and scaling invariant spectrum. In the second method image moments are used to obtain the affine invariant spectrum but without the rotation effect. The novelty of our approach is the third step which is carried out in both cases; the 1D signal produced by circular motion around the origin in frequency domain is analysed. Both methods are derived in the continuous space domain and extended to digital binary images. The terms of generalised sensitivity and compromise sensitivity are introduced. In this paper the properties of invariant descriptors are experimentally verified on real digital images of tree leaves. Many researchers deal with leaf recognition and various approaches can be found in the contemporary literature. An interesting review of existing approaches developed for plant species identification has been provided by Cope, Corney, Clark, Remagnino, and Wilkin (2012). Leaves can be characterised by their shape, colour, and texture. However, because leaf colour varies during the seasons, and leaves from different trees can have almost the same leaf colour, colour is not a reliable device for leaf recognition. Many authors have based their feature description only on the leaf contour (Felzenszwalb & Schwartz, 2007; Laga, Kurtek, Srivastava, Golzarian, & Miklavcic, 2012; Ling & Jacobs, 2007; Mouine,