PROJECTIVE METHODS OF IMAGE RECOGNITION

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Abstract: We propose a method for image recognition on the base of projections. Radon transform gives an opportunity to map image into space of its projections. Projection properties allow constructing informative features on the base of moments that can be successfully used for invariant recognition. Offered approach gives about 91-97% of correct recognition.

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Introduction

The modern computer vision problems, such as pattern recognition and normalization [1-5] are actual and still unsolved problems. Additional difficulties arise when the recognized objects are subject to geometrical transformations and noises.

The primary tasks of pattern recognition at presence of geometrical distortions are related to formation of highly-informative invariant systems of attributes, choice of metrics for their comparison, and construction of decision-making criterion. The type of the metric frequently depends on properties, ranges of formed attributes values, and also on possible noise types. While solving the specific problems, the chosen decision criterion together with the system of attributes determines significantly parameters of speed and reliability of recognition. One of the effective ways to solve the recognition problem is the construction and analysis of attributes on the basis of set of image projections. The projections are formed by applying Radon transform (RT), as well as similar Hough transform, and trace transform, etc. [6-10].

The main advantages of projective transformations are the following, i.e., high self-descriptiveness, noise protection ratio, and possibility of realization in the real-time systems. Displaying the two-dimensional image as a combination of one-dimensional functions enables to simplify and accelerate the procedures of normalization and recognition.

Projective transforms

RT represents integral of brightness function $B(x,y)$ [4,8]:

$$R(p,\theta)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}B(x,y)\delta(p-x\cos\theta-y\sin\theta)dxdy\,, \quad (1)$$

where $\delta(.)$ is Dirac delta function, which determines belonging of image points to the straight line with parameters (p,θ) along which integration is carried out. Here $p\in P$ is the distance from the beginning of the coordinates up to the line of integration, $\theta\in\Theta$ is the angle between the line of integration and the X-axis, P,Θ are ranges of p,θ values respectively.

The spatial mapping which is carried out with RT is possible to write as:

$$R: L^2(R^2)\to L^2(L^2(R),[0,2\pi])\,,$$

where R, R^2, L^2 are classical spaces of functions [10].

As a result of the discrete transformation the image $B(x, y)$ is put in correspondence with the image $R(p, \theta)$ from space of projections. $R(p, \theta)$ is the matrix of size $P \times \Theta$ determined by parameters (p, θ).

Hough transform is close enough to RT and in discrete variant is its special case [8]. Originally it was developed for curve figures identification on the image and is especially effective if the image contains a few points. The main difference between Radon and Hough transforms for direct line model is that RT puts in correspondence to each straight line on the image the fixed quantity of the points laying on it while Hough transform examines every possible straight line which passes through each point [8].

Trace transform is related to the generalizations of RT [9]. In it, similar to RT, functionals are calculated along the lines. Thus RT is reduced to calculation of the fixed functional – integral, while in trace transform any functional from the image is applied. Various of functionals enable to construct variety of the trace transforms, underlining some or other properties of the object on the image. In view of identical general view of trace functionals transition from one transform to another can be carried out rather easily [9].

Invariant features on the base of the Radon transform

Properties of projective transforms allow to construct system of features which are invariant to the number of geometrical transforms. Moment invariants are convenient and reliable system of features for visual objects recognition [1,5]. By processing one-dimensional projections on the basis of the central moments it is possible to construct system of invariant attributes for each projection.

Let's write down expressions for the classical m_k and central moments μ_k for the one-dimensional functions received on basis of RT:

$$m_k = \int_P R(p, \theta) p^k dp \ , \ \mu_k = \int_P R(p, \theta)(p - \frac{m_1}{m_0})^k dp \ , \ k = 0, 1, 2, \ldots \quad (2)$$

In view of an estimation of influence of geometrical transforms of the initial image on its Radon mapping image, the following systems of invariant attributes is offered to use.

Invariants to moving and scale transforms of the image will be functions of the variable θ:

$$\gamma_k(\theta) = \frac{\int_P R(p, \theta)^{k+1} (p - \frac{m_1}{m_0})^k dp}{(\mu_0)^{k+1}} . \quad (3)$$

Features, which are invariant to the rotating and moving transforms, are the following:

$$\xi_k = \int_\theta \int_P R(p, \theta)(p - \frac{m_1}{m_0})^k dp d\theta . \quad (4)$$

For the most general transforms of metric group (includes scaling, rotation and moving) invariant features turn out by integration of functions γ_k on space Θ and look like:

$$\eta_k = \int_\theta \gamma_k(\theta) d\theta . \quad (5)$$

Invariant comparison methods

It is possible to present the general approach for pattern recognition on the basis of the invariant attributes constructed with the use of projective transforms as follows. The input is the image which can be deformed by manipulation of metric group transforms (include rotation, scaling, moving). RT $R(p, \theta)$ calculates for it, in discrete realization it represents a matrix of projection values. For each projection the set of n invariant attributes is calculated. The quantity of attributes and projections used in recognition as a whole is defined by the etalon set and required level of correct recognition probability.

Recognition is realized by comparison of invariant attributes values for each projection with the values of reference attributes from database.

Let $\omega_1 = \{\gamma_i(\theta)\}$, $\omega_0 = \{\gamma_i^0(\theta)\}$ be sets or vectors of invariant features, constructed on the basis of projections for the image and the etalon respectively. Number i of an attribute can be directly connected to the order of the moment k in (3) - (5). Comparison of sets ω_1, ω_0 can be constructed by comparison of values at the fixed size k as well as by comparison based on parameter θ at fixed k.

For invariant (3) as a function $\gamma_k(\theta)$ the distance in the space of attributes on the basis of the popular metrics of the module of differences can be calculated as

$$\rho(\omega_1, \omega_0) = \sum_k \sum_\theta |\gamma_k(\theta) - \gamma_k^0(\theta)|. \tag{6}$$

The criterion of recognition is implemented by minimization of value (6) on the set of etalons $\Omega_0 = \{\omega_0\}$.

One of the variants of recognition by invariant attributes is also the estimation of deviations of calculated invariant features from etalon values, for example, on the basis of average and mean square deviation. Even such simple rules as «three sigma» yield encouraging results [3].

Recognition procedure with the use of invariant attributes is submitted on Fig. 1.

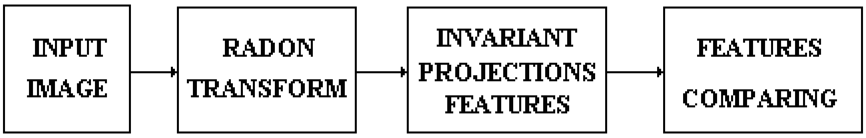

Figure 1 – Recognition procedure on the base of RT invariant features

Voting methods

Other important opportunity provided by the application of RT in consequence of its independence of calculation of its values for separate values of parameters p, θ is an independent decision-making for each of used projections. The recognition criterion thus is reduced to optimization on set Ω_0 of more simple values, than (6):

$$\rho(\omega_1, \omega_0, \theta) = \sum_k |\gamma_k(\theta) - \gamma_k^0(\theta)|, \tag{7}$$

that enables to make steady decisions, for example, on the majority of local decisions of used projections that corresponds to the voting procedure [5]. We shall notice that there are practical classes of images, whose recognition needs only one projection.

On application of the rule (7), for example, for 4 projections, natural way of acceptance of the reliable decision is agreement of the decisions at least for 3 of 4 projections. At the same time, decisions of separate projections can be not equal for concrete an application that allows carrying out recognition on separate, most important components of set of projections.

During the recognition using only one projection among all values of deviations the minimal size $\rho(\omega_1, \omega_0^i)$ gets out. The number i which corresponds to the minimum is a considered number of the etalon from the database.

While using several projections the result of comparison represents some set of numbers of etalons in which each of the used projections denotes. At ideal recognition all numbers of etalons should coincide among themselves. Recognition can be carried out also on a maximum of quantity of identical numbers of etalons. If there are some identical values of maxima, we can pick of them that one which has the least deviation among all the other maxima from the etalon. The strictest rule is the choice of that etalon which simultaneously specifies all projections.

Informative properties of the spectrum

Recognition procedure can be constructed also directly on the basis of the analysis of spectrum $R(p,\theta)$ values. The most informative part of RT for some classes of images is the set of values of local maxima [7,9]. Such characteristics of maxima as value, quantity, site, relative positioning in the general structure and others allow constructing the system of attributes having sense of planimetric representation, displaying property of the form of initial visual object [6]. The circuit of recognition on the basis of comparison of RT spectrums is submitted in Fig. 2.

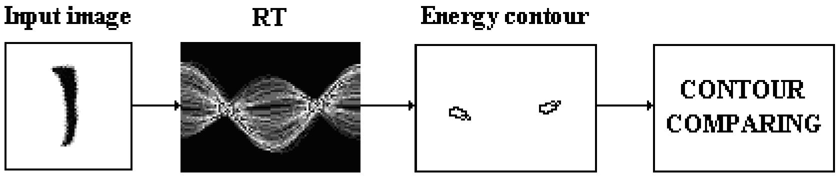

Figure 2 – Recognition procedure using local maximums of RT

Experiments and conclusion

Research of methods efficiency of recognition was carried out on several test sets. Sets of images of animals, hieroglyphs and examples of images of fingerprints are shown in Fig. 3. Entrance test images were formed from etalons by transforms of scale and movement. Recognition results are submitted in Table 1.

The type and complexity of recognition procedure depends on the considered problem and the prospective type of geometrical transforms. Our research have shown, that it is possible to reach high enough probability (is higher 0,95) at the specified transformations for complex images such as fingerprints (see Fig. 3) with the use of only 3-4 projections. The influence of rotation transformation yields the mixing of values for separate projections, and thus the required quality of recognition is achieved either by increasing the number of projections used for recognition or constructing the rotational invariants.

For the case of one-parametrical transformations (displacement within the limits of a vision field, or rotating about $\pm 15^{\circ}$, or scale changes within the limits of 0,85-1,15) recognition of fingerprints is reached with probability 1 on the base of only one projection. With the presence of combinations of two listed transformations on three projections for images of fingerprints the probability of correct recognition has made about 0,95.

In some cases RT allows to narrow essentially the base of etalon images with a view of using any other alternative criterion of recognition. This purpose is achieved, for example, by cutting off the maximal deviation using some threshold. In such a way recognition procedure can be reduced to search not only one but also several etalons closest to the input image.

Table 1 – Comparative results of test sets recognition

№	*Test set*	*Amount of etalons /amount of experiments*	*Invariant features/ Amount of projections*	*Recognition level*
1	*Animals*	*10 / 200*	*6 features / 1*	*1,0*
2	*Animals*	*26 / 390*	*6 features / 1*	*0,9871*
3	*Hieroglyphs*	*30 / 450*	*6 features / 1*	*0,8688*
4	*Hieroglyphs*	*30 / 450*	*12 features / 2*	*0,9377*
5	*Fingerprints*	*17 / 255*	*6 features / 1*	*0,95*

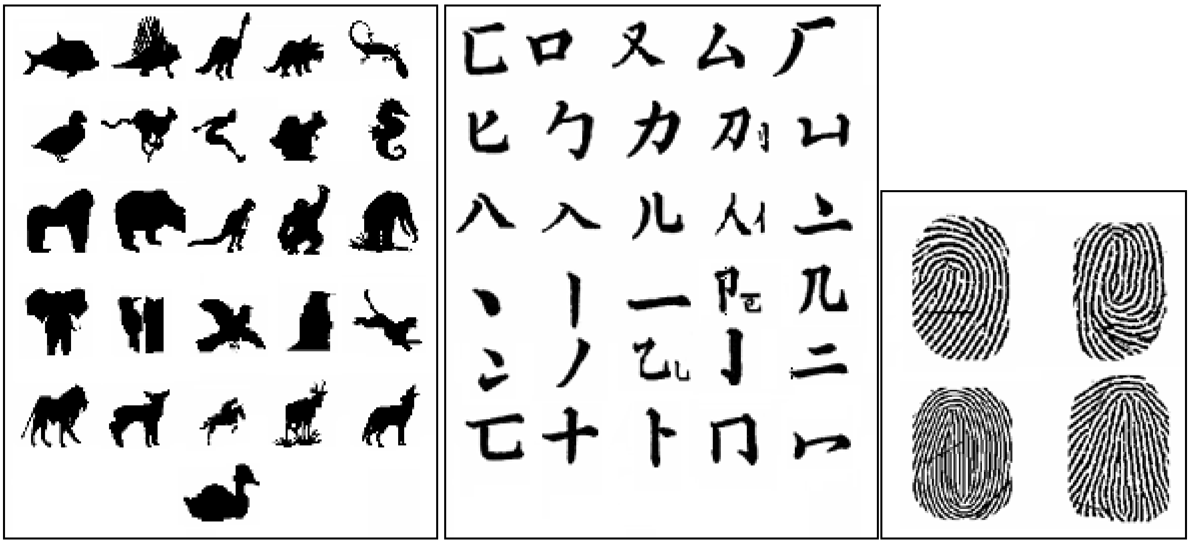

Figure 3 – Test images: animals, hieroglyphs, fingerprints

As one can see from the table, the probability is slightly decreasing with the increasing of etalons quantity in a database (Table 1, experiments №1-2). Besides the probability grows with the increasing quantity of the used projections (Table 1, experiments №3-4). For fingerprint images each of two projections (at $\theta = 0°$ and $\theta = 90°$) yields approximately identical results.

The suggested approach was tested also on the problem of hand-written signatures verification, examples of which are shown in Fig. 4. For this problem the algorithm with an estimation of mean square deviations and dispersions for set of invariant values of type (3) was used. The probability of correct verification was about 0,97.

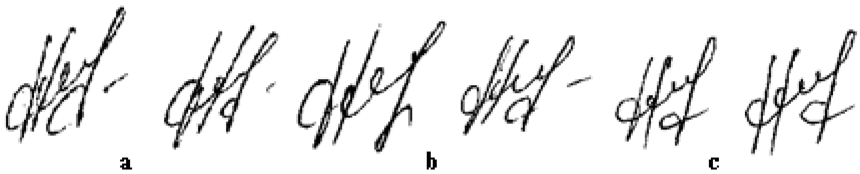

Figure 4 – Test images of hand-written signatures: a – etalon genuine signatures; b – genuine signatures; c – forgery signatures

Experiments have shown, that time of calculation of the suggested invariant features (3) and, respectively, the time of recognition is essentially less, than for classical moment invariants. For example, computer modeling time of calculation of two-dimensional invariant attributes at the size of the image 256x256 pixels was about 1,3 sec. while the time of invariants (3) calculations was near 0,3 sec., which was four times less.

Projective transforms are one of the effective ways of image analysis and recognition. Properties of projections allow receiving informative features that can be successfully used for invariant recognition. Result of representation the two-dimensional image as the projections is reducing to one-dimensional space of features that allows reducing time of calculations essentially. Projective transforms can be successfully applied to the practical problems of recognition and identification of the complex visual data. The practical level of recognition is within the limits of 91-97 %.

The problem moments of application of projection methods are necessity of image segmentation concerning a difficult background, and also the maintenance of sufficient accuracy at performance of displaying working with discrete angles.

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