AN EFFICIENT SCHEME FOR INVARIANT OPTICAL CHARACTER RECOGNITION USING TRIPLE CORRELATIONS

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Optical Character Recognition

- *Analysis* of the document into its constituents (photographs, figures and text).
- *Segmentation* of the text into columns, paragraphs, lines, words and characters.
- *Recognition* of the segmented characters.
- *Ambiguity resolution.*

Also:

- *Preprocessing:* gray scale normalization, noise elimination.
- *Postprocessing:* spelling verification or correction, customized lexicons.
- *Interaction* with human operators.

Recognition of segmented characters

- **Feature extraction**
  Input image $\longrightarrow$ Vector of fixed length, containing all the "essential" characteristics.

- **Classification**
  Class discrimination by generalizing from a training set.

Goals:

1. Derivation of a feature vector which is:
   - Invariant to shift, rotation and scale [SRS] transformations.
   - Insensitive to noise and small distortions.
2. Fast implementation in the case of binary images.

Solution:

- Calculation of the 3^{rd} order correlation of the pattern.
- Appropriate clustering & transformation of the triple-correlation domain.

Definition & properties of 3^{rd} order correlations

$x(\mathbf{t})$: real 2-D signal with support

$$S = \{0, \ldots, N-1\} \times \{0, \ldots, N-1\}$$

$$x_3(\tau_1, \tau_2) \triangleq \frac{1}{N^2} \sum_{S} x(\mathbf{t})\, x(\mathbf{t}+\tau_1)\, x(\mathbf{t}+\tau_2)\ , \quad \tau_1, \tau_2 \in S'$$

$$S' = \{-N+1, \ldots, N-1\} \times \{-N+1, \ldots, N-1\}$$

- *Symmetries*
- *Insensitivity* to noise.
- *One-to-one correspondence* with the original signal.
- *Translation, rotation & scaling:*

  $y(\mathbf{t}) = x(\mathbf{T}_{\alpha,\theta}\, \mathbf{t} + \mathbf{t}_o) \Longrightarrow$

  $y_3(\tau_1, \tau_2) = x_3(\mathbf{T}_{\alpha,\theta}\, \tau_1, \mathbf{T}_{\alpha,\theta}\, \tau_2)$

  where $\mathbf{T}_{\alpha,\theta}$: scaling & rotation matrix

  $\mathbf{t}_o$: shifting vector

The invariant representation

1. *Definition of classes:*

   $C(\tau_1, \tau_2)$: set of all lags which form triangles similar to the one defined by τ_1, τ_2

2. *Arrangement* between members of each class in a log-polar grid:

   $\tilde{x}_3(\rho, \phi; \tau_1, \tau_2) \stackrel{\triangle}{=} x_3(\mathbf{T}_{\beta,\phi}\,\tau_1, \mathbf{T}_{\beta,\phi}\,\tau_2)$

   where $\mathbf{T}_{\beta,\phi} = \beta \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix}$ and $\rho = \log\beta$

   Then:

   $y(\mathbf{t}) = x(\mathbf{T}_{\alpha,\theta}\,\mathbf{t} + \mathbf{t}_o) \Longleftrightarrow$

   $\tilde{y}_3(\rho, \phi; \tau_1, \tau_2) = \tilde{x}_3(\rho \log\alpha, \phi + \theta; \tau_1, \tau_2)$

3. Calculation of the 2-D Fourier transform $\tilde{X}_3(P, \Phi; \tau_1, \tau_2)$ of $\tilde{x}_3(\rho, \phi; \tau_1, \tau_2)$ w.r.t. ρ and ϕ $\Rightarrow$ shift invariant w.r.t. ρ and ϕ.

4. Appropriate amplitude & phase information of the transform $\rightarrow$ representation F_x.

Properties of F_x:

- Unique correspondence with class of images that are mutually related with SRS transformation.
- Noise insensitivity
- Stand-alone representation $\Rightarrow$ direct input to classifier.

Feature size reduction

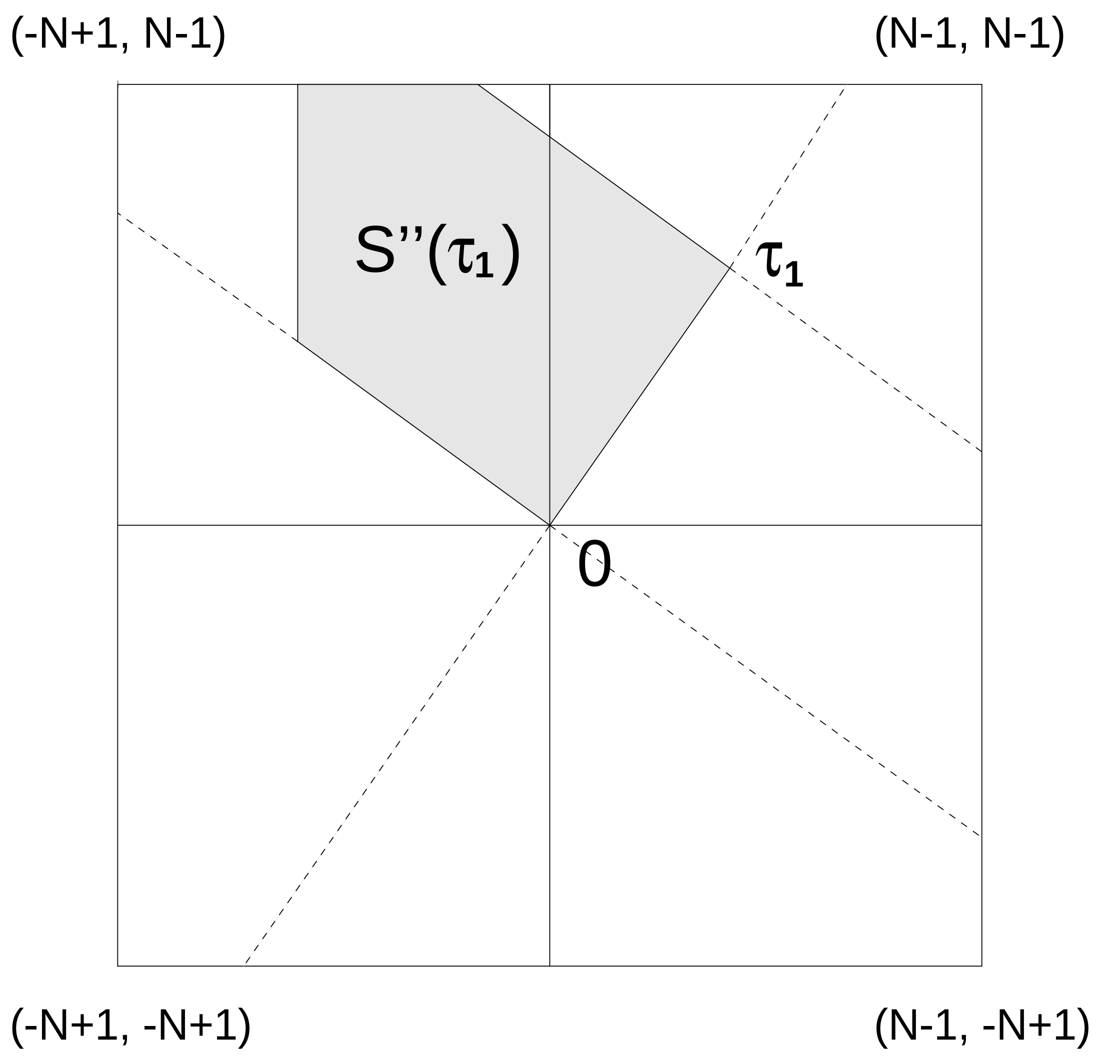
1. *Reduced representation:*
   - amplitude information only, or
   - zero-frequency Fourier coefficient only.

2. *Reduced redundancy:*
   For each $\tau_1 \in S' \Rightarrow \tau_2 \in S''(\tau_1)$

$$S''(\tau_1) = \{\tau_2 \in S' : 0 \leq \tau_1 \cdot \tau_2 \leq |\tau_1|^2, \; 0 \leq \tau_1 \cdot \tau_2{}', \; (\tau_1 - \tau_2) \in S'\}$$

3. *Class parametrization:*
   $(\tau_1, \tau_2) \rightarrow (\theta_1, \theta_2) \qquad \theta_1, \theta_2 \in [0, \frac{\pi}{2}]$
   4-D space $\rightarrow$ 2-D space

The region $S''(\tau_1)$



Discrete implementation

- Binary (black & white) images: $x(\mathbf{t}) \in \{0, 1\}$
  Then:
  - Image stored in binary integers
  - Real multiplication $\Longleftrightarrow$ Boolean "AND".
- Discrete 2-D grid of $(\theta_1,\ \theta_2) \Rightarrow$
  finite number of distinct classes $C(\theta_1, \theta_2)$.
- Discrete 2-D grid of ρ and ϕ $\Rightarrow$
  discretization in the interior of each class.
- $\tilde{x}_3(\rho, \phi; \theta_1, \theta_2) \to \tilde{X}_3(P, \Phi; \theta_1, \theta_2)$
  via FFT algorithm.
  Parrallel implementation: possible.
- $|\tilde{X}_3(P, \Phi; \theta_1, \theta_2)|$: Final 4-D invariant representation.

Algorithm

Step 1: Calculate all the horizontal shifts of the input image.

Step 2: For each $\tau_1 \in S'$:

1. Find & store all possible products $x(\mathbf{t})\,x(\mathbf{t}+\tau_1)$, using the already calculated horizontal shifts and the logical operator AND.
2. Calculate & quantize ρ, ϕ by comparing τ_1 with $\tau_o = (1, 0)$.
3. For each $\tau_2 \in S''(\tau_1)$:
   (a) Find $x_3(\tau_1, \tau_2)$, using the products $x(\mathbf{t})\,x(\mathbf{t}+\tau_1)$.
   (b) If $x_3(\tau_1, \tau_2) = 0$, proceed to the next τ_2.
   (c) Calculate & quantize θ_1, θ_2.
   (d) $\tilde{x}_3(\rho, \phi; \theta_1, \theta_2) := \tilde{x}_3(\rho, \phi; \theta_1, \theta_2) + x_3(\tau_1, \tau_2)$

Step 3: Find $\tilde{X}_3(P, \Phi; \theta_1, \theta_2)$; keep the amplitude of the transform only.

Simulation Results

Sample input images

Invariant representations

Invariant representations of scaled and rotated versions of the letter 'N'.

Euclidean distances between invariant representations