First- and Second-Order Sorted Local Binary Pattern Features for Grayscale-Inversion and Rotation Invariant Texture Classification

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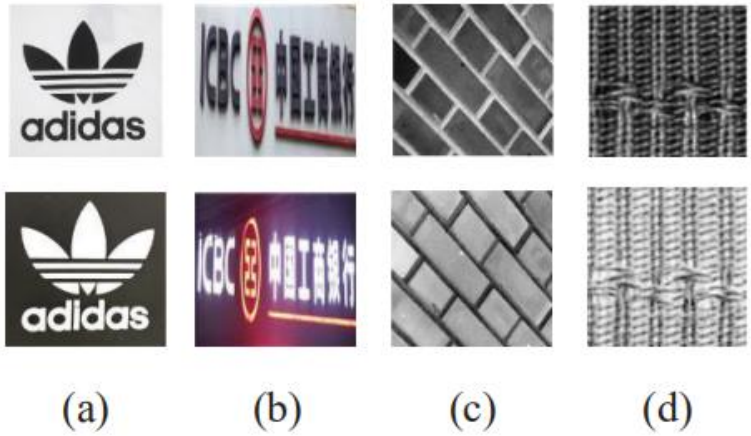
Texture classification challenges

- LBP is sensitive to inverse grayscale changes:

—foreground and background variations or varying lighting conditions



- gradient-based methods
- complement code-based methods

do not distinguish LBP codes and their complements

Proposed method

- First-Order Sorted LBP(SLBP) Feature
  - sort pairwise bins of a LBP histogram

- Second-Order Sorted LBP(SLBP) Feature
  - capture the spatial co-occurrence relationships of LBP pairs
  - employ the sorting operator and max pooling

- Generalization to other LBP features

First-Order SLBP Feature

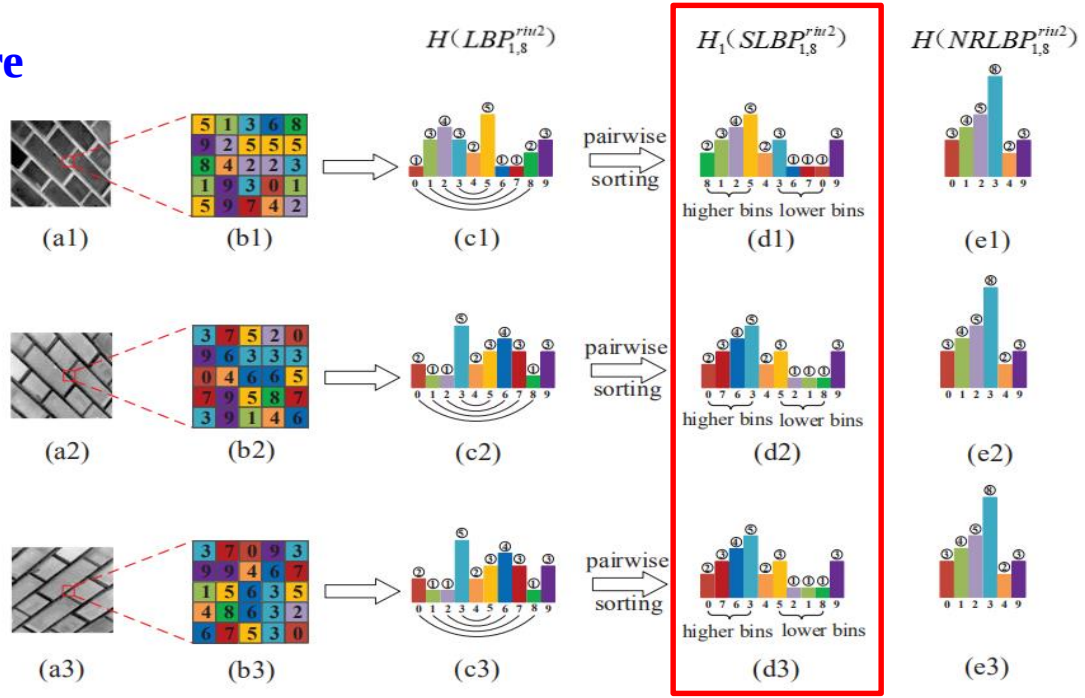
$$H_1(SLBP_{r,P}^{riu2})[i]=\begin{cases} max\{H(LBP_{r,P}^{riu2})[i], H(LBP_{r,P}^{riu2})[P-i]\}, & 0 \le i < P/2 \\ min\{H(LBP_{r,P}^{riu2})[i], H(LBP_{r,P}^{riu2})[P-i]\}, & P/2 < i \le P \\ H(LBP_{r,P}^{riu2})[i], & i = P/2, P+1 \end{cases}$$

robust to both change

H_1 :the first-order histogram feature

i : the index of histogram bins

- sort pairwise bins of the histogram in descending order

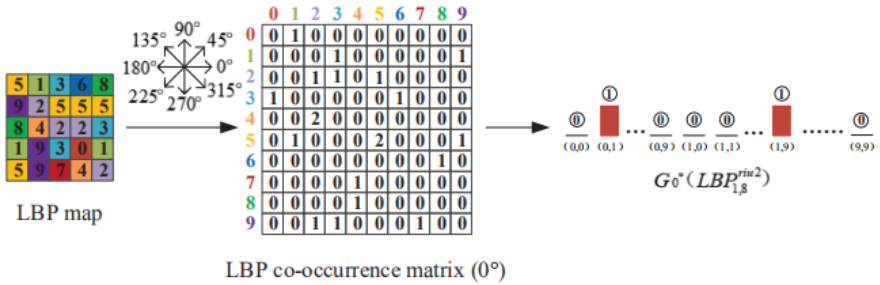


• Second-Order SLBP Feature

We cast grayscale inversion and image rotation as a row-column shifting problem regarding a LBP co-occurrence matrix.

Algorithm 1 Computation of second-order SLBP feature

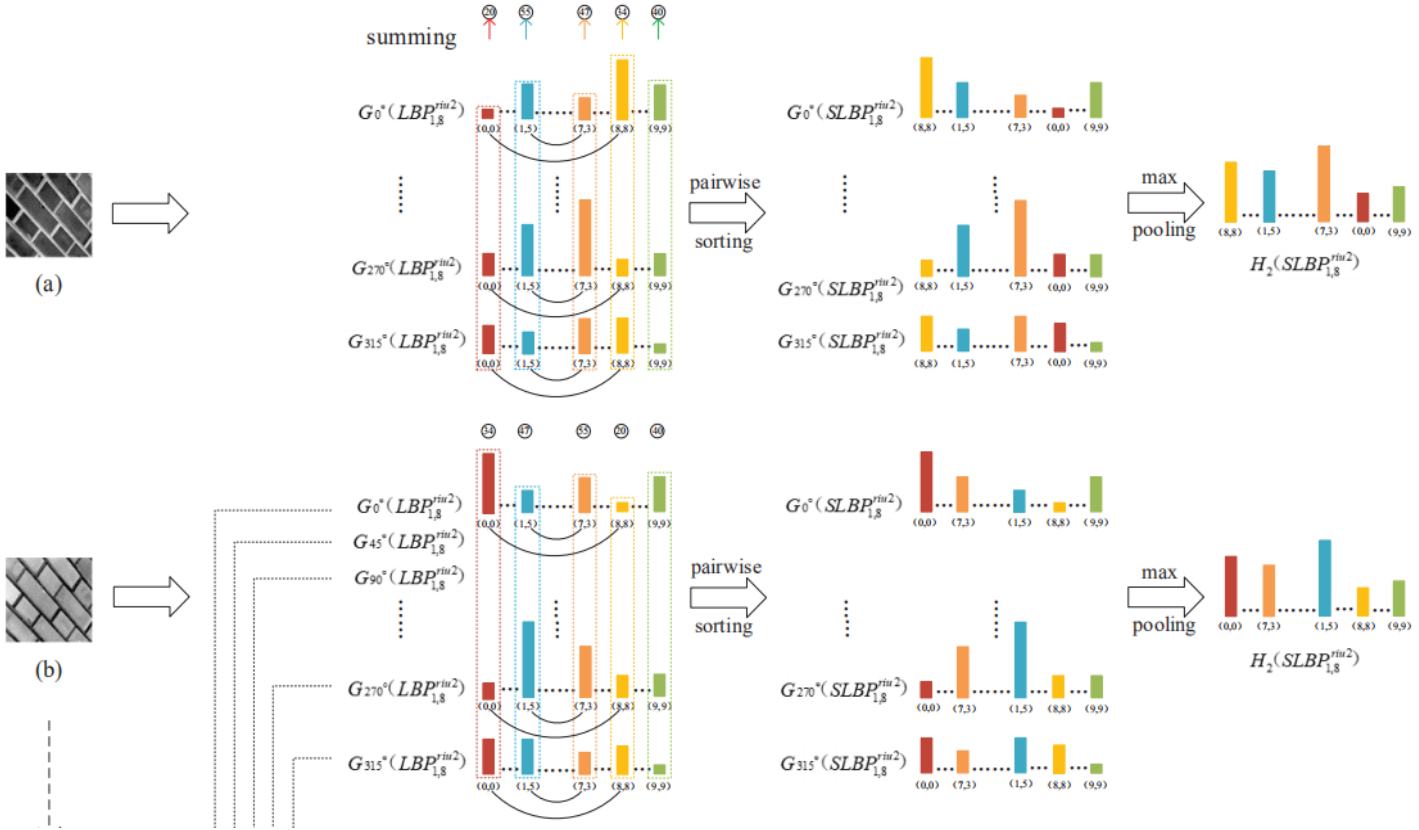
1: Compute a $LBP^{riu2}_{r,P}$ feature map from the input image.
2: Construct a co-occurrence matrix $G(LBP^{riu2}_{r,P})$.
3: Obtain $G(SLBP^{riu2}_{r,P})$ by sorting pairwise columns of $G(LBP^{riu2}_{r,P})$ according to the sums of column elements.
4: Perform max pooling on each column of $G(SLBP^{riu2}_{r,P})$.
5: Output the second-order SLBP feature $H_2(SLBP^{riu2}_{r,P})$.



construct LBP co-occurrence histogram

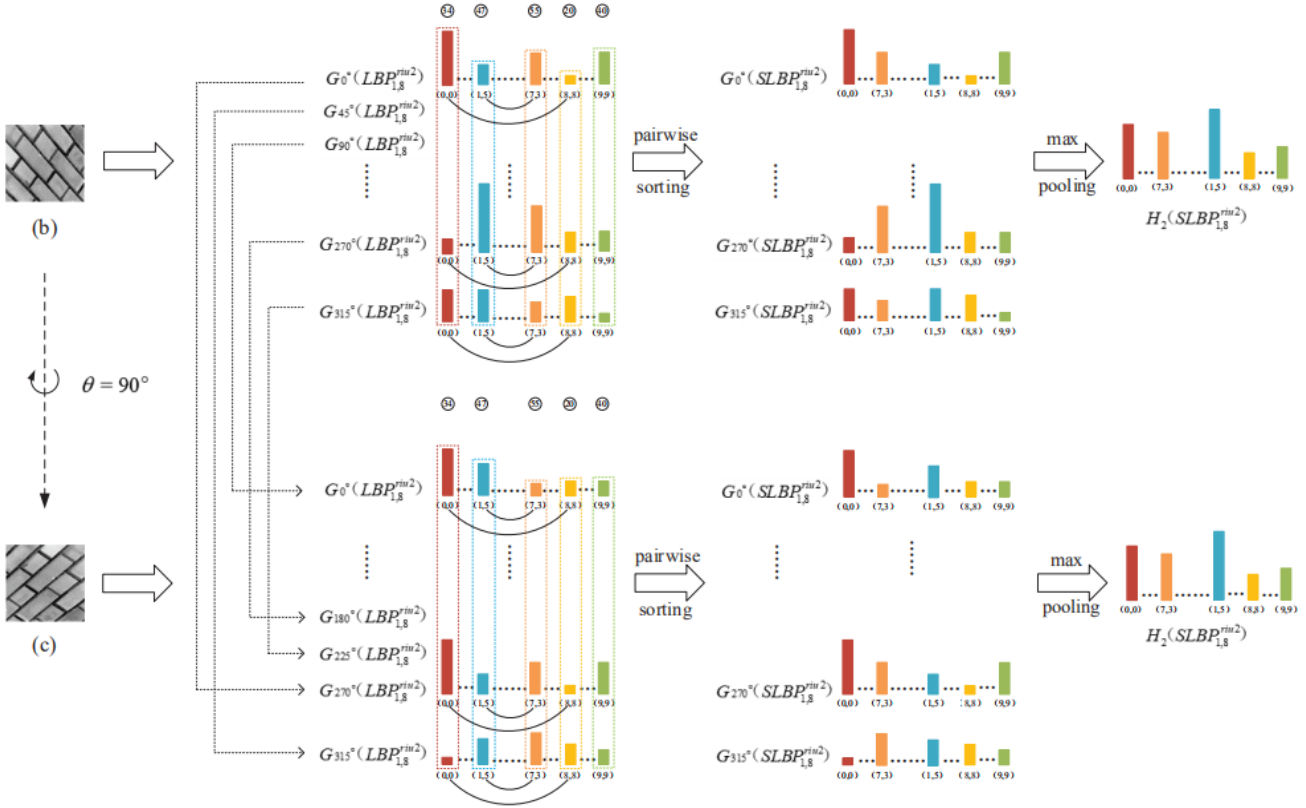
- # Second-Order SLBP Feature

robustness to grayscale-inversion changes



• Second-Order SLBP Feature

robustness to rotation changes



- # Generalization to other LBP features

we generalize our method to embed a complementary LBP magnitude feature into our framework.

Texture datasets

Outex (TC10): 24 classes, rotation changes
Outex (TC12): 24 classes, rotation & illumination changes
KTH-TIPS: 10 classes, illumination & scale changes
Curet: 61 classes, viewpoints & illuminations changes

Nearest-neighborhood (NN) classifier with the chi-square distance

$$\chi^2(H_1, H_2) = \sum_k \frac{[H_1(k) - H_2(k)]^2}{H_1(k) + H_2(k)}$$

Classification results

TABLE I
CLASSIFICATION ACCURACIES (%) ON THE OUTEX-TC10 TEST SUITE

Descriptors	Linear grayscale-inversion changes				Nonlinear grayscale-inversion changes			
	r=1, P=8	r=2, P=16	r=3, P=24	three-scale	r=1, P=8	r=2, P=16	r=3, P=24	three-scale
LBP [1]	29.25	32.74	43.90	40.78	29.40	32.14	44.09	40.63
LTP [17]	13.20	17.35	21.88	21.39	14.24	29.51	43.67	36.56
CLBP [19]	20.76	23.96	24.35	24.43	18.13	22.45	24.15	22.99
LGP [30]	60.57	87.73	89.46	94.72	54.38	82.79	83.85	91.63
GLBP [31]	50.42	77.52	93.15	-	48.44	76.55	92.79	-
NRLBP [7]	38.63	75.36	86.61	89.66	38.52	74.87	86.15	89.48
CGRI-LBP [34]	85.43	96.90	98.02	98.15	73.26	94.58	96.80	96.41
$H_1(SLBP)$	38.13	80.51	91.38	90.41	38.07	79.90	91.28	89.84
$H_1(LBPM)$	81.74	93.67	95.52	97.06	68.52	87.86	91.51	93.23
$H_1(SLBP\_LBPM)$	73.00	96.41	97.00	97.76	64.11	93.62	96.09	96.12
$H_2(SLBP)$	43.77	89.81	94.80	90.77	44.27	89.58	94.92	90.60
$H_2(LBPM)$	**82.81**	96.00	96.90	97.58	**74.36**	91.51	95.03	95.06
$H_2(SLBP\_LBPM)$	78.96	**96.85**	**98.06**	**98.28**	70.91	**95.42**	**96.29**	**96.72**
SLGP [33]			97.79				96.41	
MRELBP [28]			17.06				16.30	
LETRIST [14]			32.97				4.17	
DRLBP [8]			20.83				6.33	
DRLTP [8]			23.09				4.17	

our second-order SLBP feature achieves the best performance under both conditions

Classification results

TABLE II
CLASSIFICATION ACCURACIES (%) ON THE OUTEX-TC12 TEST SUITE

Descriptors	Linear grayscale-inversion changes				Nonlinear grayscale-inversion changes			
	r=1, P=8	r=2, P=16	r=3, P=24	three-scale	r=1, P=8	r=2, P=16	r=3, P=24	three-scale
	t184 horizon	t184 horizon	t184 horizon	t184 horizon	t184 horizon	t184 horizon	t184 horizon	t184 horizon
LBP [1]	24.21 22.70	31.80 32.58	42.33 42.67	39.31 39.68	24.28 22.99	31.71 32.52	42.69 42.89	38.91 39.39
LTP [17]	22.34 24.63	25.28 27.80	32.45 33.49	37.38 38.45	12.92 15.25	29.56 30.44	42.78 41.47	35.54 37.08
CLBP [19]	17.75 17.86	22.50 22.36	23.10 23.31	22.11 22.80	17.15 17.18	22.64 23.01	23.62 23.80	23.14 23.87
LGP [30]	51.16 52.37	70.51 71.18	74.72 75.42	78.96 76.83	41.69 45.22	63.77 61.24	67.51 68.81	70.76 69.14
GLBP [31]	46.05 47.64	74.68 77.06	90.37 89.26	-	41.81 41.49	72.99 74.78	89.33 88.70	-
NRLBP [7]	32.57 29.42	64.88 55.46	70.42 63.89	73.09 66.80	31.92 29.35	64.65 55.64	70.51 64.05	73.01 66.50
CGRI-LBP [34]	63.50 62.83	83.09 82.31	87.76 82.99	85.16 82.99	59.31 62.26	72.82 71.46	80.63 76.18	77.99 75.56
$H_1(SLBP)$	29.26 25.46	70.55 64.00	78.58 72.91	79.44 74.44	29.26 25.25	70.28 63.40	78.08 72.57	79.00 73.84
$H_1(LBPM)$	59.31 62.78	73.80 72.41	81.18 78.66	81.11 81.18	51.06 51.18	64.63 61.41	74.31 66.48	72.80 71.39
$H_1(SLBP\_LBPM)$	56.97 59.41	80.89 80.20	88.15 86.35	84.33 83.38	50.35 52.06	72.73 67.48	82.52 77.52	76.50 73.80
$H_2(SLBP)$	32.32 33.67	83.25 79.22	85.35 80.63	79.77 76.63	32.11 32.91	**83.08 79.17**	**85.16** 79.84	**79.44** 76.67
$H_2(LBPM)$	**63.19 67.80**	78.17 78.08	84.84 83.98	83.19 84.47	**54.05 53.52**	69.26 67.34	76.97 70.25	74.81 73.33
$H_2(SLBP\_LBPM)$	58.29 61.19	**86.89 87.05**	**90.22 89.66**	**85.44 85.30**	49.31 52.08	76.34 75.02	84.03 **80.74**	78.56 **78.13**
SLGP [33]	84.17 83.82				75.49 73.63			
MRELBP [28]	25.02 24.68				16.30 25.14			
LETRIST [14]	32.37 34.89				4.17 4.17			
DRLBP [8]	21.41 23.84				6.13 6.75			
DRLTP [8]	24.39 27.48				4.35 4.33			

our SLBP feature runs faster than GLBP

Classification results

TABLE III
CLASSIFICATION ACCURACIES (%) ON THE CURET DATABASE

Descriptors	Linear grayscale-inversion changes				Nonlinear grayscale-inversion changes			
	r=1, P=8	r=2, P=16	r=3, P=24	three-scale	r=1, P=8	r=2, P=16	r=3, P=24	three-scale
LBP [1]	31.84	33.54	34.21	43.70	32.11	33.39	34.18	43.54
LTP [17]	16.62	18.49	18.53	44.77	11.64	17.12	22.13	41.67
CLBP [19]	29.63	31.60	32.81	33.70	31.65	33.50	34.28	43.68
LGP [30]	76.71	67.37	69.55	89.65	60.57	62.30	65.18	85.65
GLBP [31]	76.80	86.24	88.38	-	73.19	85.78	87.21	-
NRLBP [7]	36.24	63.90	74.38	74.96	36.00	65.79	74.52	75.15
CGRI-LBP [34]	83.76	91.21	93.00	94.84	81.54	89.78	91.96	93.42
$H_1(SLBP)$	35.70	67.06	80.33	77.29	35.72	66.38	80.00	76.73
$H_1(LBPM)$	74.99	82.98	86.48	91.61	68.16	76.33	81.15	87.73
$H_1(SLBP\_LBPM)$	68.91	88.74	91.00	92.30	65.28	86.01	89.48	91.30
$H_2(SLBP)$	47.28	80.07	84.56	79.28	46.85	79.81	84.39	78.84
$H_2(LBPM)$	**85.10**	88.49	89.67	93.42	**80.11**	83.82	85.60	90.45
$H_2(SLBP\_LBPM)$	78.77	**91.46**	**92.85**	**94.34**	76.53	**90.02**	**91.45**	**93.09**
SLGP [33]			94.86				91.20	
MRELBP [28]			38.39				38.85	
LETRIST [14]			43.68				2.30	
DRLBP [8]			41.83				11.29	
DRLTP [8]			55.56				4.64	

we observe that H_1(SLBP) outperforms NRLBP when $r > 1$

Classification results

TABLE IV
CLASSIFICATION ACCURACIES (%) ON THE KTH-TIPS DATABASE

Descriptors	Linear grayscale-inversion changes				Nonlinear grayscale-inversion changes			
	r=1, P=8	r=2, P=16	r=3, P=24	three-scale	r=1, P=8	r=2, P=16	r=3, P=24	three-scale
LBP [1]	39.25	39.74	45.91	47.17	38.99	38.14	44.59	46.65
LTP [17]	28.20	31.35	29.88	54.46	24.59	36.51	38.67	41.67
CLBP [19]	42.76	40.96	39.35	43.39	44.13	42.45	39.75	43.68
LGP [30]	78.57	79.73	80.04	88.12	76.12	75.38	75.59	87.71
GLBP [31]	83.42	88.52	88.54	-	81.84	87.55	88.78	-
NRLBP [7]	67.90	76.07	79.63	84.85	66.73	75.61	78.98	84.80
CGRI-LBP [34]	89.64	92.85	93.21	95.30	89.54	91.78	91.96	92.68
$H_1(SLBP)$	59.49	81.24	87.34	88.90	57.46	81.02	86.90	89.27
$H_1(LBPM)$	83.00	89.88	87.39	92.85	81.22	88.27	84.00	90.37
$H_1(SLBP\_LBPM)$	83.59	90.66	91.73	94.27	80.98	89.76	90.73	91.95
$H_2(SLBP)$	79.66	86.93	89.17	91.20	78.54	86.86	88.41	90.93
$H_2(LBPM)$	89.00	92.76	90.54	94.02	86.34	90.59	87.74	92.15
$H_2(SLBP\_LBPM)$	**91.00**	**93.93**	**94.07**	**95.44**	**89.95**	**92.41**	**92.46**	**94.56**
SLGP [33]			94.05				90.82	
MRELBP [28]			39.02				40.24	
LETRIST [14]			53.75				12.24	
DRLBP [8]			45.24				18.49	
DRLTP [8]			55.64				10.00	

the multi-scale representation helps to improve the feature's descriptive ability

Summary

- We propose SLBP feature

- It can preserve the distribution information of LBP codes and their complements.
- Second-order SLBP feature captures the spatial co-occurrence relationships of LBP codes.
- It can be generalized to embed any rotation invariant LBP features, e.g., LBPM

Thanks!