CHAPTER 7

Color Texture Classification Results and Discussions

Color texture classification is a challenging area in image analysis. There are two major parameters in order to extract a feature. The first parameter is the number of color levels. The second parameter is a color space. In this work, we introduced these two parameters which were suitable for Fuzzy Co-Occurrence Matrix (FCOM) feature extraction. The details of the study are explaining in section 7.1. Then, the results and discussions are described in section 7.2. Finally, the chapter summary is given in section 7.3.

7.1 Experimental design

In order to evaluate texture features, we selected two color space, i.e., RGB [60] and HSV [61]. An RGB color space is any additive color space based on the RGB color model. A particular RGB color space is defined by the three chromaticities of the red, green, and blue additive primaries. This color model is a convenient for computer graphics because the human visual system works in a way that is similar to an RGB color space. HSV is a cylindrical-coordinate representations of points in an RGB color model. This representation rearranges the geometry of RGB in an attempt to be more intuitive and perceptually relevant than the Cartesian (cube) representation. This color space developed for computer graphics applications. HSV is used today in color pickers, in image editing software, and less commonly in image analysis and computer vision. HSV stands for hue, saturation, and value. In each cylinder, the angle around the central vertical axis corresponds to "hue", the distance from the axis corresponds to "saturation", and the distance along the axis corresponds to "value".

For each color space, we utilized the FCM to each color channel. Then, FCOMs were computed from each membership planes. The properties of texture in this case were extracted from each FCOM plane and combined them to create the feature sets.

The feature sets extracted from the FCOM called FzCM1, FzCM2, FzCM3, FzCM4, FzCM5, and FzCM6 as mentioned in section 4.1. Hence, we had twelve feature sets, six from RGB color space and the other six from HSV color space. Each FCOM feature set had the size of 3 color channel × number of texture properties × number of θ × number of d × number of clusters C. The four texture properties were calculated from each matrices, i.e., f_2: contrast, f_3: correlation, f_1: energy, and f_5: homogeneity at $\theta = 0°$ to produce FzCM1. To produce FzCM2, these four texture properties at $\theta = 0°$, 45°, 90°, and 135° were computed. We computed the average and standard deviation from FzCM2 of all directions to produce the FzCM3. Similar to those three feature sets, we also created another three feature sets with fourteen properties, f_1 to $f_{14,}$ that we explained in section 3.3, namely FzCM4, FzCM5, and FzCM6, respectively. Again, we created the feature sets from Gray Level Co-occurrence Matrix (GLCM) namely GLCM1, GLCM2, GLCM3, GLCM4, GLCM5, and GLCM6 in the similar way for comparing the recognition results. Hence, we had twelve feature sets from GLCM, six from RGB color space and the other six from HSV color space. Each GLCM feature set had the size of 3 color channel × number of texture properties × number of θ × number of d.

Moreover, we created the twelve feature sets using the FCOM in RGB and HSV color space. We called this method Fuzzy Color Level Co-Occurrence Matrix (FCLCOM) as shown in figure 7.1. The FCLCOM is computed from each membership planes from the output of the FCM clustering all color channels altogether. There were one quantized image and C membership planes in this case. The feature sets were called FzCLCM1, FzCLCM2, FzCLCM3, FzCLCM4, FzCLCM5, and FzCLCM6. FzCLCM1 was created from four texture properties, i.e., f_2: contrast, f_3: correlation, f_1: energy, and f_5: homogeneity at $\theta = 0°$. FzCLCM2 was created from these four texture properties at $\theta =$ 0°, 45°, 90°, and 135°. We computed the average and standard deviation from FzCLCM2 of all directions to produce the FzCLCM3. We extracted 14 texture properties, f_1 to f_{14}, as mentioned in section 3.3 to produce FzCLCM4 at $\theta = 0°$. FzCLCM5 was created from these four texture properties at $\theta = 0°$, 45°, 90°, and 135°. We computed the average and standard deviation from FzCLCM5 of all directions to produce the FzCLCM6. Again, there were six feature sets from RGB color apace and the other six from HSV color space. Each feature set had the size of number of cluster × number of texture properties × number of θ × number of d.

We also created the four feature sets namely CLCM1, CLCM3, CLCM3, and CLCM4 using the Color Level Co-occurrence Matrix (CLCM) [59]. In CLCM feature extraction, the orientation assignment of CLCM is shown in figure 7.2. There are 13 directions in this orientation. Each feature set had the size of number of gray levels × number of texture properties × number of θ × number of d.

The comparison of the FCOM, GLCM, FCLCOM, and CLCM feature sets are shown in table 7.1. The color texture feature extraction diagram used in this experiment is shown in figure 7.3.

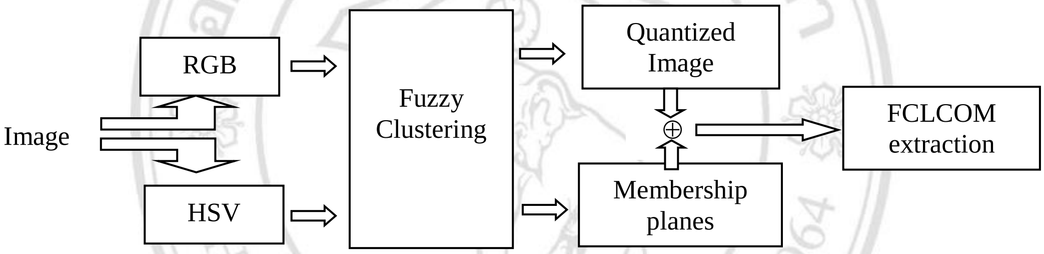


Figure 7.1 FCLCOM extraction framework.

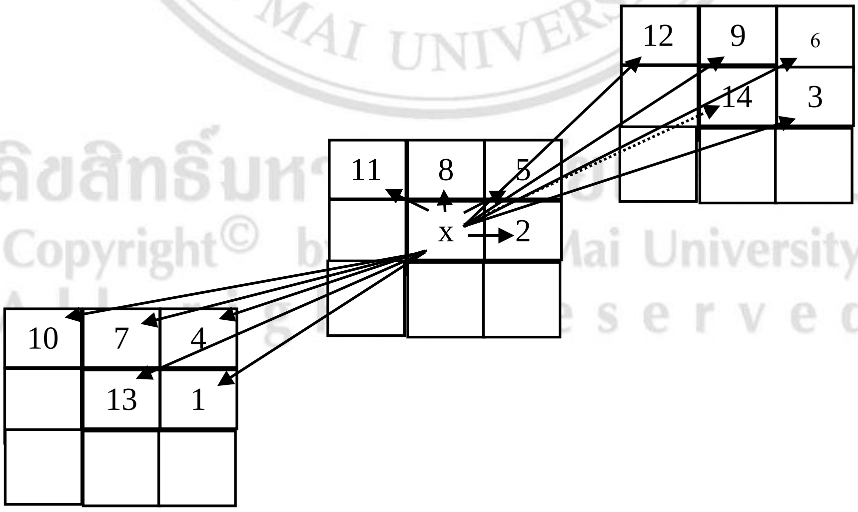


Figure 7.2 CLCM orientation assignment.

For Color Level Co-occurrence Matrix (CLCM) [59] feature sets, CLCM1 was produced from f_2: contrast, f_3: correlation, f_1: energy, and f_5: homogeneity in all directions (θ). CLCM2 was created from the average and standard deviation from CLCM1. Similar to CLCM1, we computed the full properties, f_1 to f_{14}, in all directions to produce CLCM3. Then, the average and standard deviation from CLCM3 was calculated to produce CLCM4.

To extract the feature sets, we implemented the FCM with C = 4, 8, and 16 to compute the FCOM and FCLCOM. Hence, the number of color levels for GLCM and CLCM were also 4, 8, and 16.

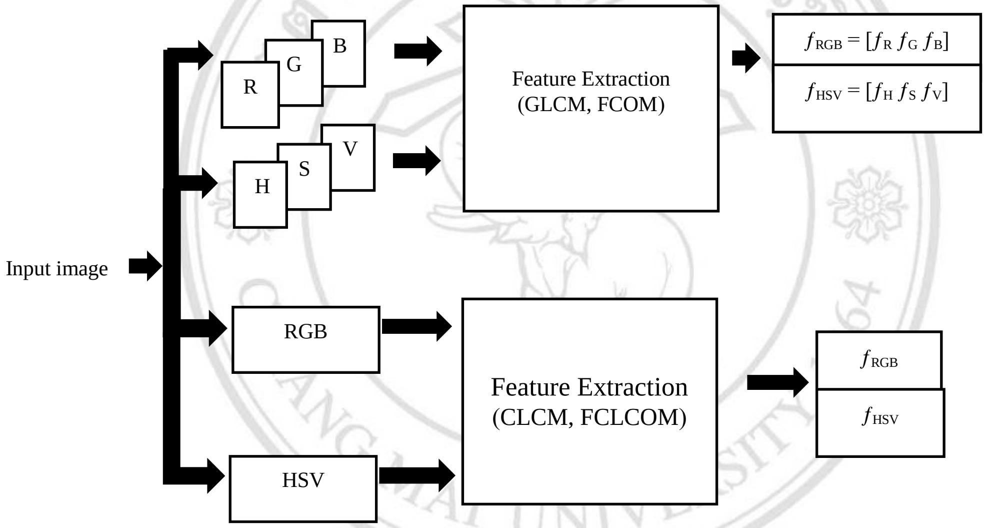


Figure 7.3 Color texture classification framework.

Table 7.1 The color feature sets comparison.

Method	N_g / C	Feature set dimension					
		GLCM1, FzCM1, FzCLCM1, CLCM1	GLCM2, FzCM2, FzCLCM2, CLCM2	GLCM3, FzCM3, FzCLCM3, CLCM3	GLCM4, FzCM4, FzCLCM4, CLCM4	GLCM5, FzCM5, FzCLCM5	GLCM6, FzCM6, FzCLCM6
GLCM	4	12	48	24	42	168	84
	8						
	16						
FzCM	4	48	192	96	168	672	336
	8	96	384	192	336	1344	672
	16	192	768	384	672	2688	1344
FzCLCM	4	16	64	32	56	224	112
	8	32	128	64	112	448	224
	16	64	256	128	224	896	448
CLCM	4	52	8	182	28	-	-
	8						
	16						

Similar to gray scale texture classification in chapter 4, we used the multi-classes support vector machine as classifier for all studies as mentioned in section 2.4. The RBF kernel with σ = 0.1, 0.25 to 20 step 0.25 was used in this case. Again, each feature's dimension was normalized using (4.1).

7.2 Classification results and discussions

In this section, two benchmark color texture data sets and three real world color texture recognition applications were selected. The first benchmark color textural data set was Outex test suit number 13 [60]. USPTex [61] was the second color texture benchmark data set. For the real world textural data sets, the biomass fuel texture, namely Biomass [61-63], was the first classification application data set used in this experiment. The second real world data set was a textures of granite types, called MondialMarmi [64-65]. The tree bark surface data set, called NewBarkTex [66], was used in the last color texture classification application. The summary of color texture data sets is shown in table 7.2.

Table 7.2 Summary of color texture data sets.

Data set name	Texture classes	Images per class	Image size (pixels)	Description
Outex	68	20	128×128	Benchmark
USPTex	191	12	128×128	Benchmark
Biomass	3	90	512×512	Biomass fuel
MondialMarmi	12	36	544×544	Granite
NewBarkTex	6	272	128×128	Tree bark surface

The Outex test suite number 13 consists of 68 classes of a large collection from surface textures and natural scenes. The surface textures are variations acquired from various illuminations, rotations, and spatial resolutions. There were 20 images with the size of 128×128 pixels per class, totally 1360 images. The Outex texture data set was available for download at: http://www.outex.oulu.fi/. Some examples of the data set are shown in figure 7.3. In this case, 10-fold cross validation was implemented. Table 7.4 to 7.6 show the best validation set recognition results from the GLCM, FCOM, FCLCOM, and CLCM texture features, respectively. The summary of the best validation set classification results is shown in table 7.7. The results summary and discussion are given at the end of this section.

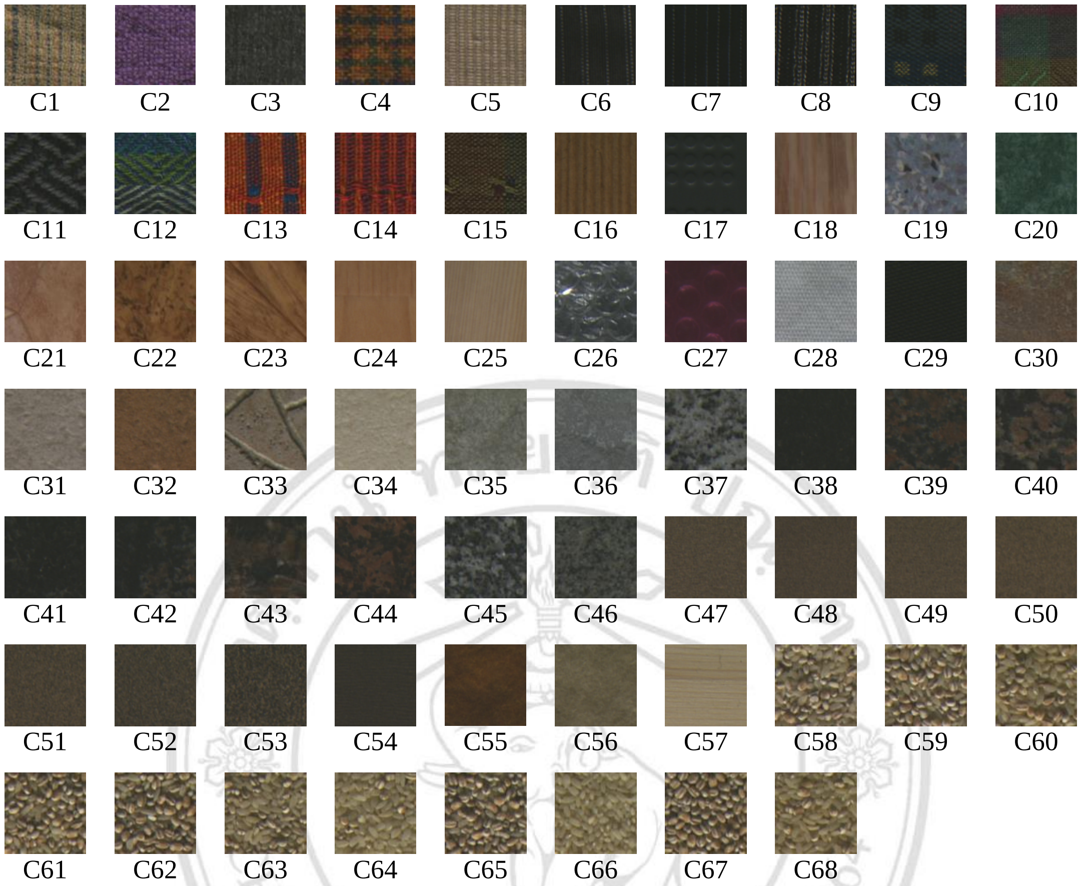


Figure 7.4 An example of the Outex color texture data set.

Table 7.3 The best correct classification results from GLCM on the Outex validation set.

Color space	N_g	Feature set											
		GLCM1		GLCM2		GLCM3		GLCM4		GLCM5		GLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	78.68	0.75	87.50	2.25	82.35	0.75	91.18	1.00	93.38	3.25	90.44	3.25
	8	82.35	0.50	88.24	1.25	87.50	0.50	92.65	1.00	94.12	1.25	91.91	2.00
	16	83.82	0.25	91.18	1.50	90.44	0.75	96.32	1.75	97.06	3.00	92.65	3.00
HSV	4	75.74	0.75	80.88	3.00	79.41	1.50	87.50	2.25	87.50	3.00	88.24	2.50
	8	82.35	1.00	87.50	3.50	88.24	1.25	91.91	1.50	92.65	3.00	91.91	2.00
	16	88.24	1.00	91.18	1.50	91.91	1.75	93.38	2.25	93.38	6.50	94.85	3.00

Table 7.4 The best correct classification result from FCOM on the Outex validation set.

Color space	C	Feature set											
		FzCM1		FzCM2		FzCM3		FzCM4		FzCM5		FzCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	76.47	1.25	84.56	6.50	89.71	3.00	78.68	4.75	85.29	5.00	88.24	7.75
	8	80.15	3.25	88.97	5.50	90.44	8.25	80.15	6.25	87.50	15.00	91.18	8.75
	16	79.41	5.25	90.44	14.25	91.18	5.50	83.82	7.00	90.44	17.75	89.71	15.75
HSV	4	84.56	2.25	88.24	4.50	87.50	1.75	83.09	5.50	88.24	5.75	87.50	9.25
	8	81.62	3.00	89.71	11.25	88.97	9.50	83.09	8.00	91.91	17.25	91.18	10.75
	16	84.56	2.25	89.71	18.50	87.50	6.50	83.82	9.75	86.76	11.00	88.97	15.25

Table 7.5 The best correct classification result from FCLCOM on the Outex validation set.

Color space	C	Feature set											
		FzCLCM1		FzCLCM2		FzCLCM3		FzCLCM4		FzCLCM5		FzCLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	75.74	1.00	83.82	1.75	83.82	1.25	78.68	2.00	85.29	2.00	86.03	1.00
	8	71.32	1.50	86.03	4.50	85.29	2.25	74.26	4.25	86.76	4.50	88.97	5.75
	16	73.53	2.00	86.03	3.00	85.29	4.50	77.21	4.00	86.76	13.00	89.71	4.75
HSV	4	66.91	0.75	75.00	1.75	72.79	1.25	69.85	1.25	74.26	2.25	75.00	2.75
	8	63.24	3.00	69.85	4.00	72.06	3.75	69.12	3.00	74.26	7.25	78.68	8.75
	16	58.82	3.00	66.91	5.50	71.32	4.75	65.44	3.75	71.32	19.25	74.26	15.25

Table 7.6 The best correct classification result from CLCM on the Outex validation set.

Color space	N_g	Feature set							
		CLCM1		CLCM2		CLCM3		CLCM4	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	83.82	1.25	75.74	0.50	92.65	2.25	83.09	1.00
	8	91.18	1.75	83.09	0.50	94.85	4.25	87.50	1.25
	16	93.38	1.50	91.18	0.50	96.32	4.50	92.65	1.75
HSV	4	88.24	2.00	83.82	0.50	86.76	4.00	83.09	1.50
	8	89.71	3.25	89.71	0.50	91.91	4.75	89.71	1.25
	16	90.44	1.50	88.97	0.50	89.71	6.50	89.71	1.75

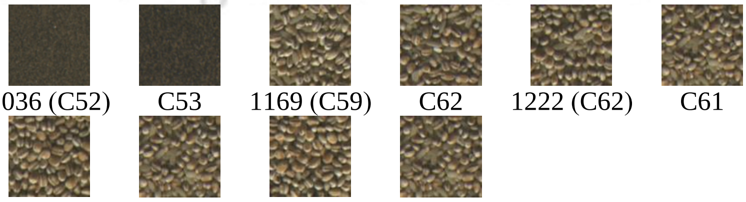
Table 7.7 The summary of the best validation set classification results on the Outex data set.

Method	**Color space**	**Color levels**	**Accuracy (%)**	**RBF σ**	**Feature set**
GLCM	RGB	16	97.06	3.00	GLCM5
CLCM	RGB	16	96.32	4.50	CLCM3
FCOM	HSV	8	91.91	17.25	FzCM5
FCLCOM	RGB	16	89.71	4.75	FzCLCM6

From the Outex recognition results, there were over 90% correct classification rate except for the features from FCLCOM. Similar to gray level texture classification, FCOM used the lower color levels than GLCM, CLCM, and FCLCOM. In this data set, the images were very correlated to the other classes such as C13 – C14, C47 – C53, and C58 – C68. The smoothness of these images were higher but the contrast was very low. Moreover, color was quite different. In this case, we suggest to optimize the distance of pixel pair to improve the classification rate. The incorrect recognition images in this data set from GLCM, CLCM, FCOM, and FCLCOM are shown in figure 7.5 to 7.8 respectively. Column a, c, e, and g show incorrect images while column b, d, f, and h show target class images. The common incorrect classification images were in C58 – C68 classes.


0987 (C50) (a) · C51 (b) · 1250 (C63) (c) · C60 (d) · 1320 (C67) (e) · C65 (f) · 1338 (C67) (g) · C65 (h)

Figure 7.5 Incorrect classification images of the Outex from GLCM texture feature.


1036 (C52) · C53 · 1169 (C59) · C62 · 1222 (C62) · C61

1327 (C67) · C61 · 1330 (C67) · C61

(a) · (b) · (c) · (d) · (e) · (f)

Figure 7.6 Incorrect classification images of the Outex from CLCM texture feature.

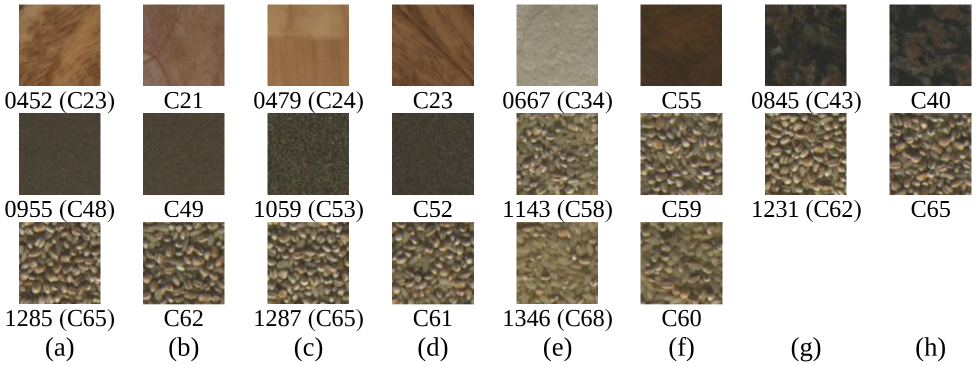


Figure 7.7 Incorrect classification images of the Outex from FCOM texture feature.

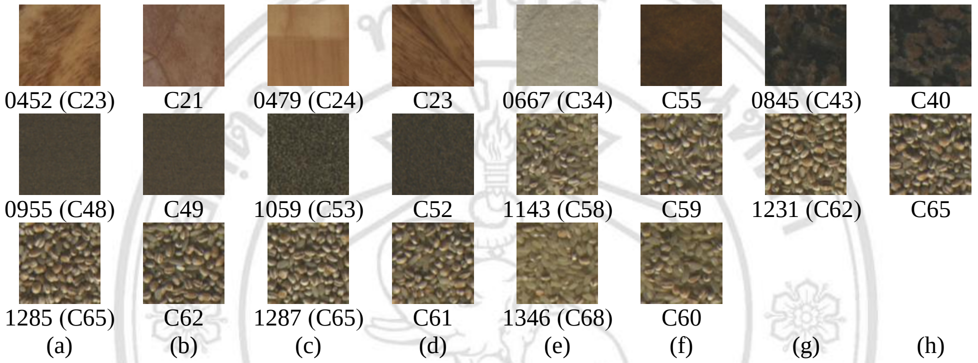
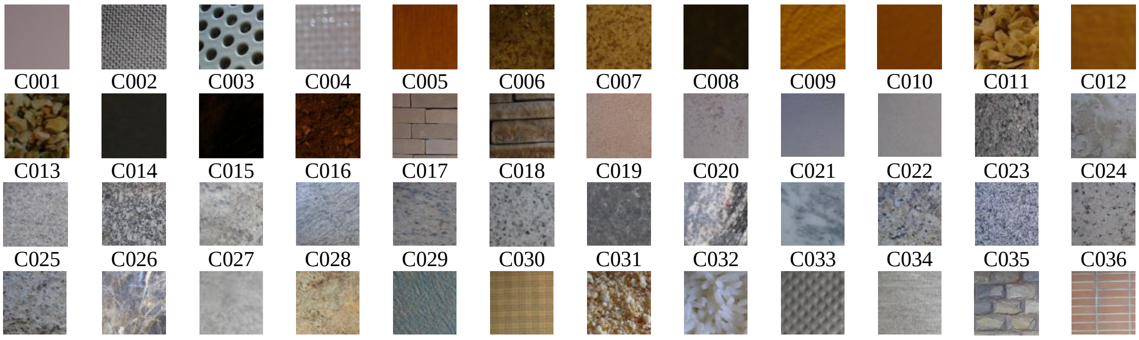


Figure 7.8 Incorrect classification images of the Outex from FCLCOM texture feature.

The USPTex contains 191 texture classes typically found daily, e.g. seeds, rice, tissues, road scenes, various types of vegetation, walls, clouds, soils, blacktop, and gravel. Each class contains 12 samples with the size of 128×128 pixels per class. They were non-overlap generated from the original images with the size of 512×384 pixels. Therefore, the data set had totally 2292 images. Some examples of USPTex data set are shown in figure 7.9. In this case, 4-fold cross validation was implemented. Table 7.8 to 7.11 show the best validation set recognition results from the GLCM, FCOM, FCLCOM, and CLCM texture features, respectively. The summary of the best validation set classification results is shown in table 7.12.



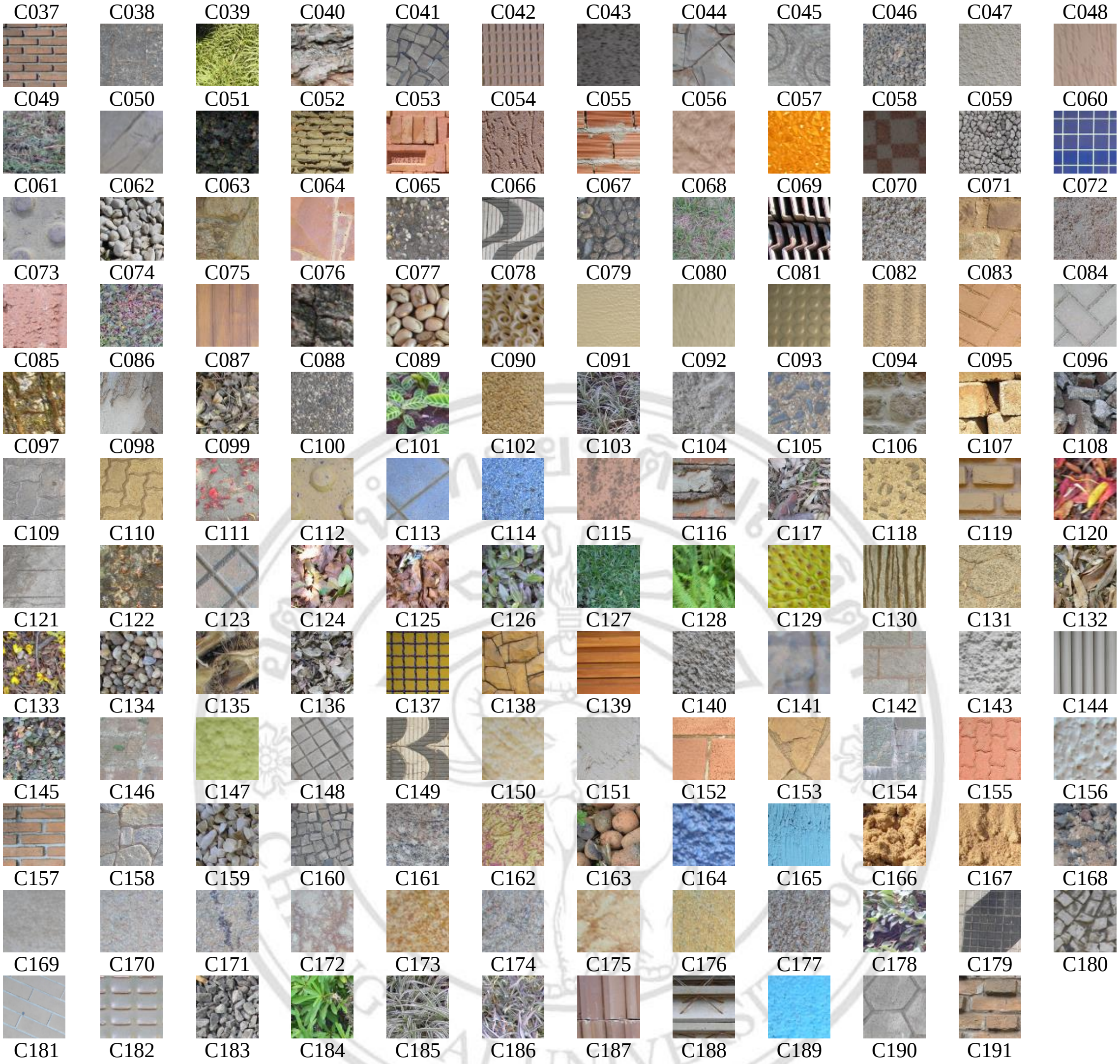


Figure 7.9 An example of the USPTex color texture data set.

Table 7.8 The best correct classification result from GLCM on the USPTex validation set.

Color space	N_g	Feature set											
		GLCM1		GLCM2		GLCM3		GLCM4		GLCM5		GLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	55.85	0.50	71.55	1.75	71.90	1.25	74.52	2.00	80.10	4.25	80.28	2.25
	8	66.14	0.50	82.02	1.50	81.68	1.25	83.07	1.25	88.66	4.50	87.78	2.50
	16	74.52	0.50	86.04	1.50	85.34	1.00	86.91	1.25	91.10	3.75	91.10	4.00
HSV	4	72.43	0.75	83.42	2.50	80.45	1.50	83.60	1.25	88.13	5.25	88.13	3.75
	8	86.04	1.25	89.70	3.00	92.15	1.25	92.15	2.25	94.42	6.25	95.11	3.00
	16	90.75	1.00	93.89	2.00	93.89	1.50	95.46	1.75	96.51	3.25	96.86	4.25

Table 7.9 The best correct classification result from FCOM on the USPTex validation set.

Color space	C	Feature set											
		FzCM1		FzCM2		FzCM3		FzCM4		FzCM5		FzCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	75.39	2.00	88.48	3.25	87.43	3.00	80.45	3.00	89.53	14.00	90.75	5.50
	8	81.50	2.75	91.10	10.00	90.75	4.75	85.51	6.75	92.50	13.00	92.15	8.75
	16	83.07	4.50	92.67	12.50	94.59	6.25	87.96	8.75	92.15	19.50	93.37	11.25
HSV	4	90.05	3.50	92.84	7.25	93.19	4.25	91.62	6.00	93.19	11.25	95.11	8.25
	8	90.93	5.00	95.64	9.00	95.99	4.50	93.37	10.50	96.34	13.25	96.34	13.75
	16	91.62	6.00	95.11	10.25	95.29	8.00	93.72	6.25	96.16	19.25	97.03	15.75

Table 7.10 The best correct classification result from FCLCOM on the USPTex validation set.

Color space	C	Feature set											
		FzCLCM1		FzCLCM2		FzCLCM3		FzCLCM4		FzCLCM5		FzCLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	65.10	0.75	80.80	1.75	79.93	1.50	71.90	1.75	83.77	3.75	84.12	2.75
	8	69.81	1.75	84.47	4.00	83.25	2.25	79.41	2.75	87.96	8.00	88.66	5.00
	16	71.73	3.00	84.47	5.75	84.29	4.00	76.09	6.00	86.74	15.00	89.53	7.50
HSV	4	63.87	0.75	70.16	2.25	72.25	1.50	70.68	2.75	75.92	7.75	77.66	4.75
	8	66.14	3.00	74.52	5.25	79.06	3.25	72.25	3.75	77.84	9.75	83.25	7.25
	16	63.18	4.25	72.43	7.50	75.39	5.25	75.57	8.00	82.72	19.75	86.91	11.75

Table 7.11 The best correct classification result from CLCM on the USPTex validation set.

Color space	N_g	Feature set							
		CLCM1		CLCM2		CLCM3		CLCM4	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	73.30	2.00	56.37	0.50	80.80	4.25	68.59	1.50
	8	86.56	1.50	69.63	0.50	87.96	3.75	82.20	2.25
	16	90.05	3.25	76.09	0.50	91.62	3.00	85.34	2.75
HSV	4	77.66	2.25	67.19	1.00	81.15	4.75	70.51	2.00
	8	88.66	3.00	78.19	0.75	91.97	3.00	81.68	1.75
	16	90.05	3.25	79.93	0.75	93.72	5.25	87.78	2.00

Table 7.12 The summary of best validation set classification results on the USPTex data set.

Method	**Color space**	**Color levels**	**Accuracy (%)**	**RBF σ**	**Feature set**
GLCM	HSV	16	96.86	4.25	GLCM6
CLCM	HSV	16	93.72	5.25	CLCM3
FCOM	HSV	16	97.03	15.75	FzCM6
FCLCOM	RGB	16	89.53	7.50	FzCLCM6

In table 7.12, the results of features from FCOM gave the best recognition rate. Similar to Outex data set, FCLCOM features gave lower recognition rates since the results of clustering is lower distribution than the other methods. The feature sets in most cases were extracted from the average and deviation of all orientation and properties ($f_1 - f_{14}$) since these feature sets were near rotation invariance. From USPTex classification results, the incorrect images from GLCM, CLCM, FCOM, and FCLCOM are shown in figure 7.10 to 7.13 respectively.

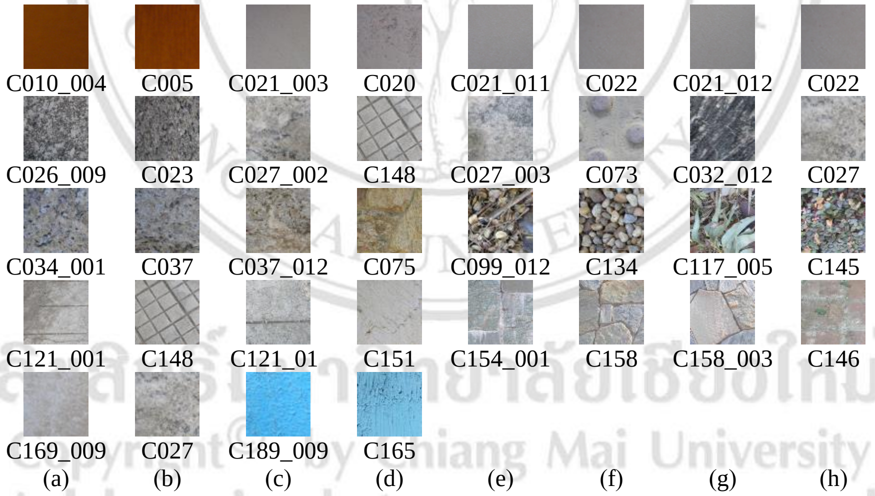
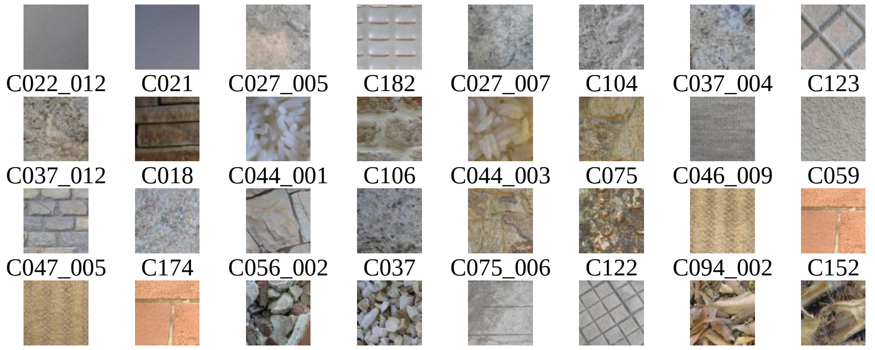


Figure 7.10 Incorrect classification images of the USPTex from GLCM texture feature.



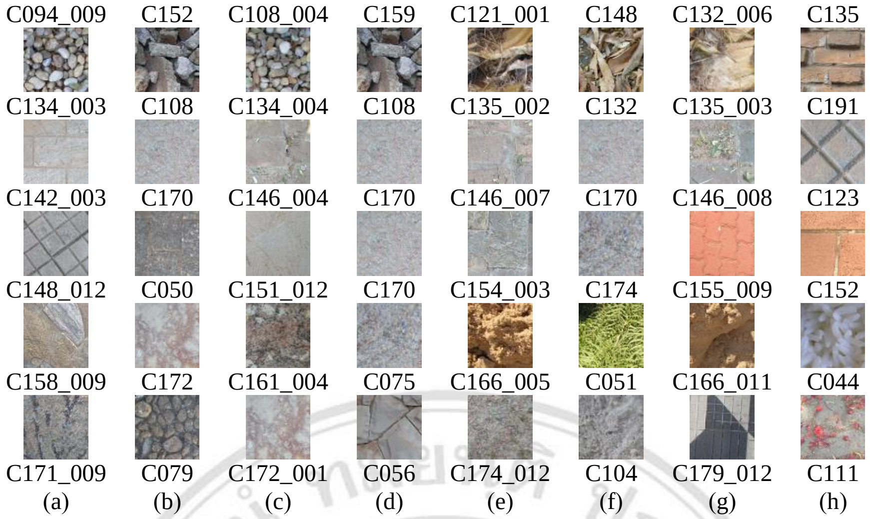


Figure 7.11 Incorrect classification images of the USPTex from CLCM texture feature.

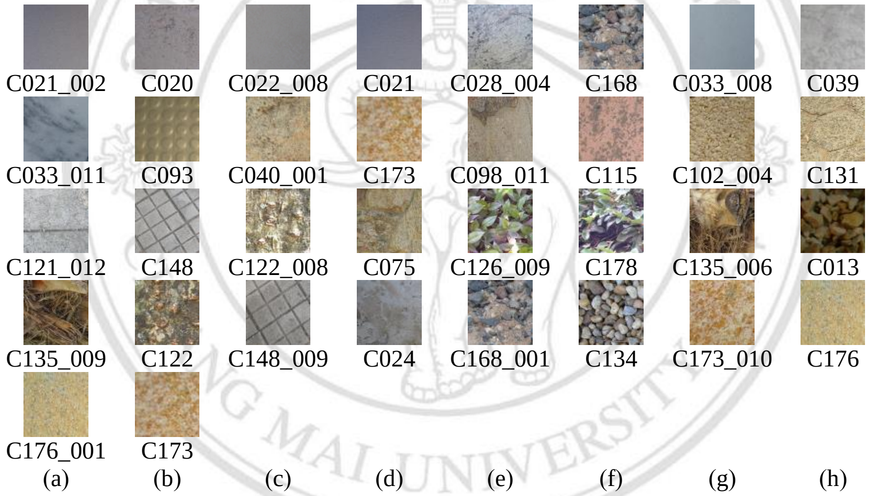
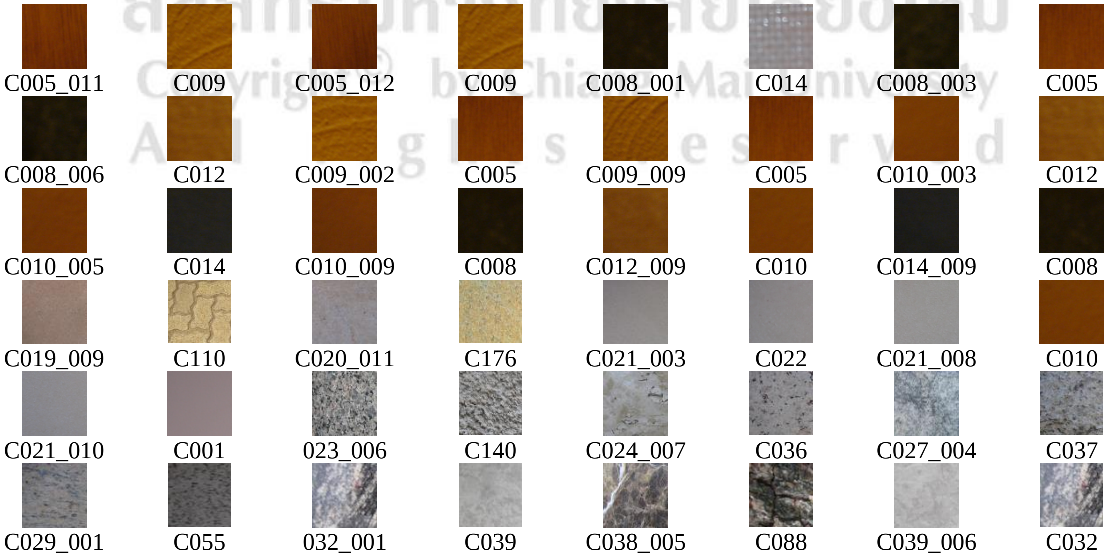


Figure 7.12 Incorrect classification images of the USPTex from FCOM texture feature.



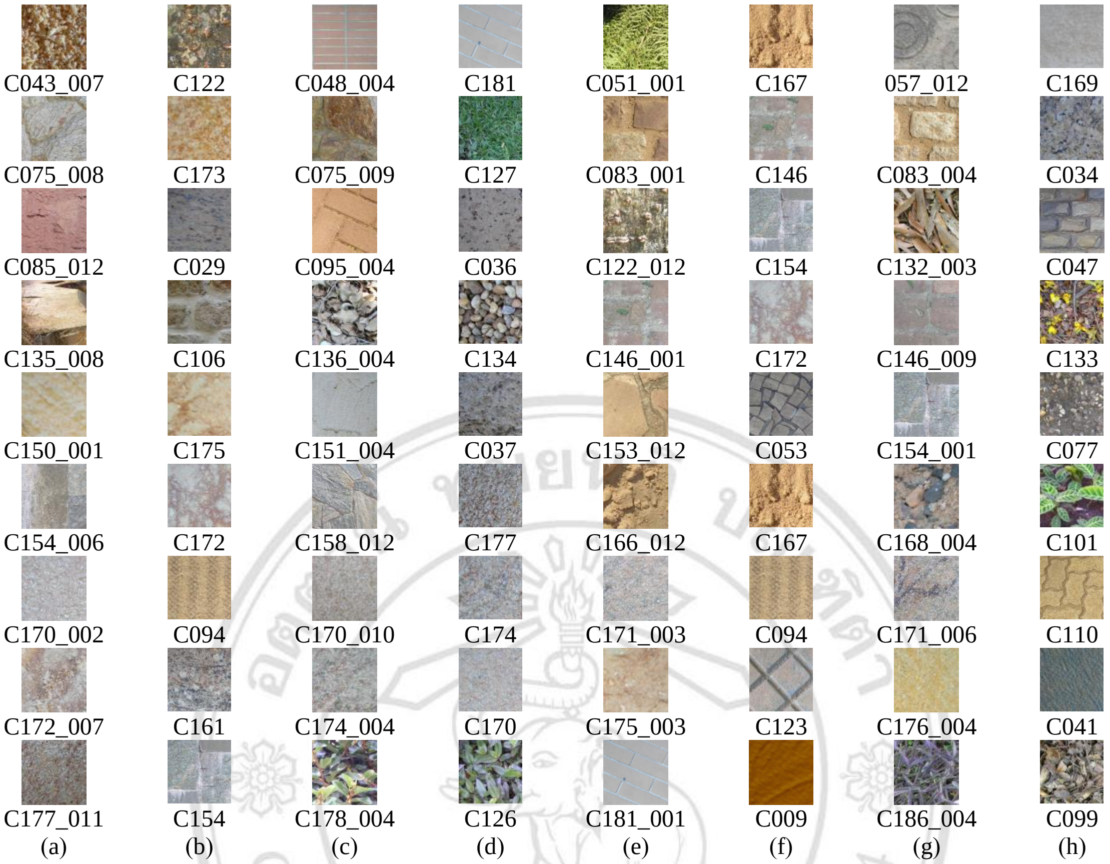


Figure 7.13 Incorrect classification images of the USPTex from FCLCOM texture feature.

The images in USPTex data set vary in color since RGB color space was appropriate for texture feature extraction. The results from GLCM and FCOM were better than those from CLCM and FCLCOM. Most of the incorrect classification images were different in contrast and smoothness. We suggest to optimize the distance of pixel pair to improve the recognition rate. In this case, the feature from FCLCOM provided lower recognition rate. The FCLCOM method not only quantized the color levels but also converted the color image to gray scale at the same time when all color channels were clustered together.

The first real world color texture data set used in this experiment was Biomass. It consists of three classes of wheat, municipal waste, and corn after the processing for biomass fuel. The close up images were digitized at different zoom levels under various lighting conditions. There were 90 images with the size of 512×512 pixels per class, totally 270 images. Some examples from the Biomass data set are shown in figure 7.14. The biomass texture data set is available for download at:http://biomass.herokuapp.com.

(a) wheat (b) waste (c) corn

Figure 7.14 An example of the Biomass color texture data set.

Table 7.13 to 7.16 show the best validation set recognition results from the GLCM, FCOM, FCLCOM, and CLCM texture features, respectively. The summary of the best validation set classification results is shown in table 7.17.

Table 7.13 The best correct classification result from GLCM on the Biomass validation set.

Color space	N_g	Feature set											
		GLCM1		GLCM2		GLCM3		GLCM4		GLCM5		GLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	0.50	100	0.75	100	0.50	100	0.50	100	1.00	100	1.00
	8	100	0.50	100	0.75	100	0.50	100	0.75	100	1.50	100	1.25
	16	100	0.50	100	0.75	100	0.75	100	0.75	100	1.75	100	1.50
HSV	4	85.19	1.00	81.48	0.75	77.78	1.50	88.89	0.25	85.19	0.75	85.19	6.00
	8	100	0.25	100	0.50	100	0.50	100	0.50	100	1.00	100	1.25
	16	100	0.50	100	1.00	100	0.50	100	1.00	100	1.25	100	1.50

Table 7.14 The best correct classification result from FCOM on the Biomass validation set.

Color space	C	Feature set											
		FzCM1		FzCM2		FzCM3		FzCM4		FzCM5		FzCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	1.00	100	1.75	100	1.25	100	2.00	100	3.75	100	2.75
	8	100	1.50	100	3.50	100	3.00	100	3.25	100	3.25	100	4.00
	16	100	1.75	100	3.75	100	5.00	100	4.50	100	7.25	100	7.25

HSV	4	100	1.25	100	2.50	100	2.00	100	2.00	100	4.00	100	3.00
	8	100	1.50	100	3.00	100	3.25	100	3.25	100	6.25	100	5.75
	16	100	2.75	100	3.00	100	4.00	100	4.75	100	10.25	100	7.25

Table 7.15 The best correct classification result from FCLCOM on the Biomass validation set.

Color space	*C*	Feature set											
		FzCLCM1		FzCLCM2		FzCLCM3		FzCLCM4		FzCLCM5		FzCLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	0.75	100	1.50	100	1.00	100	1.50	100.	2.75	100	1.75
	8	100	1.00	100	1.50	100	1.00	100	1.75	100	3.50	100	2.50
	16	100	1.50	100	3.25	100	2.25	100	3.75	100	7.50	100	6.00
HSV	4	100	0.75	100	1.25	100	1.00	100	1.25	100	2.75	100	2.00
	8	96.30	1.50	100	4.50	100	2.75	100	5.00	100	8.25	100	5.75
	16	96.30	2.75	96.30	6.00	96.30	3.25	100	7.25	100	13.50	100	11.75

Table 7.16 The best correct classification result from CLCM on the Biomass validation set.

Color space	N_g	Feature set							
		CLCM1		CLCM2		CLCM3		CLCM4	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100.00	0.75	100.00	0.25	100.00	1.50	100.00	0.75
	8	100.00	1.00	100.00	0.25	100.00	1.50	100.00	1.00
	16	100.00	0.75	100.00	0.25	100.00	1.75	100.00	1.25
HSV	4	100.00	0.75	100.00	0.25	100.00	1.50	100.00	1.00
	8	100.00	1.00	100.00	0.25	100.00	1.75	100.00	0.75
	16	100.00	0.75	100.00	0.50	100.00	1.75	100.00	1.00

Table 7.17 The summary of the best validation set classification results on the Biomass data set.

Method	**Color space**	**Color levels**	**Accuracy (%)**	**RBF σ**	**Feature set**
GLCM	RGB	4	100.00	0.50	GLCM1
CLCM	RGB	4	100.00	0.75	CLCM1
FCOM	RGB	4	100.00	1.00	FzCM1
FCLCOM	RGB	4	100.00	0.75	FzCLCM1

From the results, we were not so excited in the best recognition rates. All texture feature extraction methods gave the same value, 100% validation set correct classification in this case. The images in this data set were easy to group by human according to three major reasons. The first reason was the number of classes. There were only three biomass fuel types comparing to the other data sets that we summarized in table 7.2. The second reason was that the sizes of objects in the images are very different. For example, waste objects were larger than wheat objects and corn objects due to their own characteristics. A waste object looks like a rectangle shape while wheat and corn objects were thin and long. The third reason was the color distribution. They were close to the other classes as shown in figure 7.14. With these reasons, we suggest that gray scale images of this data set should be used to reduce the computational time since the results might not be different.

The second real world color texture data set was MondialMarmi. It had totally 432 images of 12 granite types with the size of 544×544 pixels. Each class consists of 4 tiles groups of 9 images at different rotation angles: 0°, 5°, 10°, 15°, 30°, 45°, 60°, 75°and 90°. Some examples from the MondialMarmi data set are shown in figure 7.15. This data set was available for download at: http://dismac.dii.unipg.it/granite/data.html. Table 7.18 to 7.21 show the best validation set recognition results from the GLCM, FCOM, FCLCOM, and CLCM texture features, respectively. The summary of the best validation set classification results is shown in table 7.22.

(a) Acquamarina (b) Azul Capixaba

(c) Azul Platino (d) Bianco Cristal

(e) Bianco Sardo (f) Giallo Napoletano

(g) Giallo Ornamentale (h) Giallo Santa Cecilia

(i) Giallo Veneziano (j) Rosa Beta

(k) Rosa Porrińo (A) (l) Rosa Porrińo (B)

Figure 7.15 An example of the MondialMarmi color texture data set.

Table 7.18 The best correct classification result from GLCM on the MondialMarmi validation set.

Color space	N_g	Feature set											
		GLCM1		GLCM2		GLCM3		GLCM4		GLCM5		GLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	0.25	100	0.25	100	0.25	100	0.50	100	0.50	100	0.75
	8	100	0.25	100	0.25	100	0.10	100	0.25	100	0.50	100	0.75
	16	100	0.10	100	0.25	100	0.10	100	0.25	100	0.50	100	1.00
HSV	4	100	0.25	100	0.50	100	0.25	100	0.25	100	0.75	100	0.75
	8	100	0.10	100	0.25	100	0.25	100	0.50	100	0.50	100	0.75
	16	100	0.25	100	0.25	100	0.25	100	0.50	100	0.75	100	0.75

Table 7.19 The best correct classification result from FCOM on the MondialMarmi validation set.

Color space	C	Feature set											
		FzCM1		FzCM2		FzCM3		FzCM4		FzCM5		FzCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	1.00	100	2.25	100	1.00	100	1.75	100	3.00	100	2.75
	8	100	1.50	100	3.00	100	2.50	100	3.50	100	4.00	100	4.75
	16	100	2.00	100	3.50	100	2.50	100	4.00	100	7.50	100	5.50
HSV	4	100	1.25	100	2.50	100	1.00	100	2.00	100	5.25	100	4.25
	8	100	2.50	100	4.50	100	4.25	100	5.25	100	8.25	100	6.75
	16	100	3.50	100	6.50	100	5.00	100	5.75	100	10.25	100	6.75

Table 7.20 The best correct classification result from FCLCOM on the MondialMarmi validation set.

Color space	*C*	Feature set											
		FzCLCM1		FzCLCM2		FzCLCM3		FzCLCM4		FzCLCM5		FzCLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	0.50	100	0.75	100	0.50	100	0.75	100	0.75	100	0.75
	8	100	0.50	100	1.00	100	0.75	100	1.00	100	1.75	100	1.50
	16	100	0.75	100	1.50	100	1.50	100	2.00	100	3.50	100	3.50
HSV	4	100	0.25	100	0.50	100	0.50	100	0.50	100	1.00	100	0.75
	8	100	1.25	100	2.00	100	1.75	100	2.25	100	4.00	100	3.50
	16	100	1.75	100	3.25	100	2.50	100	3.00	100	6.00	100	5.50

Table 7.21 The best correct classification result from CLCM on the MondialMarmi validation set.

Color space	N_g	Feature set							
		CLCM1		CLCM2		CLCM3		CLCM4	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	100	0.25	100	0.10	100	0.25	100	0.50
	8	100	0.25	100	0.10	100	0.25	100	0.50
	16	100	0.25	100	0.10	100	0.25	100	0.50
HSV	4	100	0.25	100	0.10	100	0.50	100	0.25
	8	100	0.25	100	0.10	100	0.50	100	0.25
	16	100	0.25	100	0.10	100	0.50	100	0.50

Table 7.22 The summary of best validation set classification results on the MondialMarmi data set.

Method	**Color space**	**Color levels**	**Accuracy (%)**	**RBF σ**	**Feature set**
GLCM	RGB	4	100	0.25	GLCM1
CLCM	RGB	4	100	0.25	CLCM1
FCOM	RGB	4	100	1.00	FzCM1
FCLCOM	RGB	4	100	0.50	FzCLCM1

Similar to the results on Biomass data set, the best validation set classification results from GLCM, FCOM, FCLCOM, and CLCM showed 100% correct recognition rates on this data set. In general, its image colors were different, although some of them were rather close, such as in Acquamarina and Azul Capixaba, Rosa Porrińo (A) and Rosa Porrińo (B). Nevertheless, their smoothness was different. With the same texture type, it was easy to recognize this data set by all the methods in this study same as by human observation.

The last color texture classification application data set was BarkTex. It contained six classes of tree bark, with 272 images per class. The original images were selected from the Outex and USPTex data set with the size of 128×128 pixels. Then, four sub-images were extracted without overlapping region with the size of 64×64 pixels. Therefore, the data set had totally 1632 images. Some examples of BarkTex images are shown in figure 7.16. The BarkTex color texture data set was available for download at: https://www-lisic.univ-littoral.fr/~porebski/NewBarkTex.zip. Table 7.23 to 7.26 show the best validation set recognition results from the GLCM, FCOM, FCLCOM, and CLCM texture features, respectively. The summary of the best validation set classification results is shown in table 7.27.

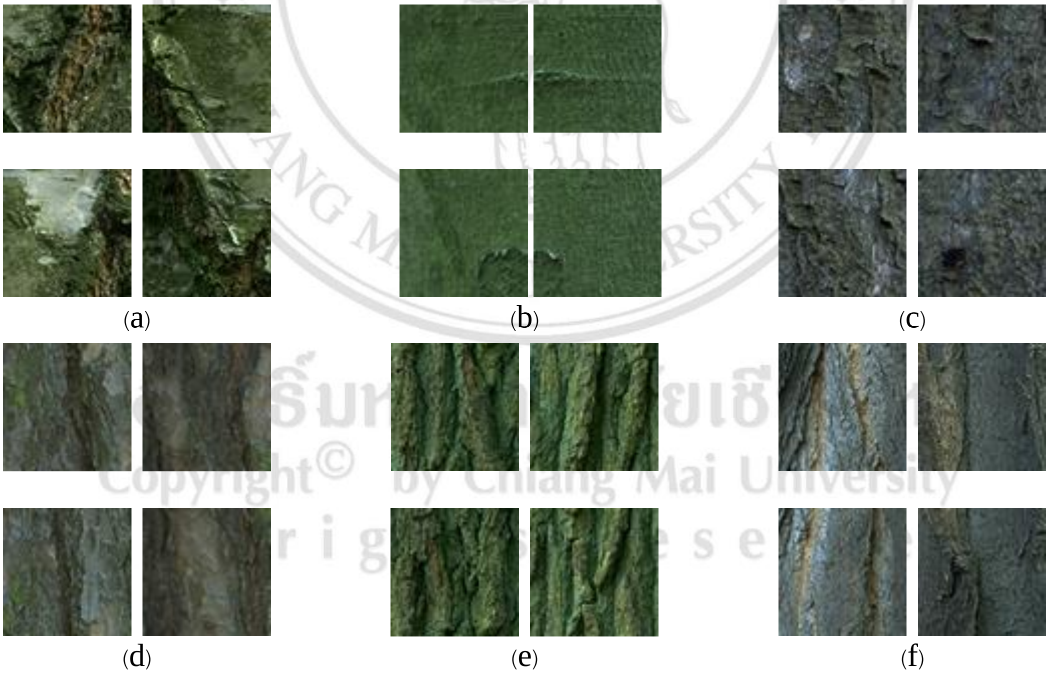


Figure 7.16 An example of the NewBarkTex color texture data set.

Table 7.23 The best correct classification result from GLCM on the NewBarkTex validation set.

Color space	N_g	Feature set											
		GLCM1		GLCM2		GLCM3		GLCM4		GLCM5		GLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	79.75	1.00	89.57	1.50	82.21	1.25	83.44	2.00	92.64	2.50	89.57	3.00
	8	79.14	1.25	92.07	1.50	85.28	1.75	85.89	1.00	93.90	3.00	91.41	2.50
	16	76.22	0.50	92.02	1.50	85.28	2.50	85.28	3.25	96.34	5.25	93.87	5.25
HSV	4	75.46	1.25	88.34	2.50	86.50	1.25	85.98	1.25	93.87	6.25	92.02	4.25
	8	82.32	1.75	90.85	1.25	87.20	2.00	90.80	2.25	95.71	4.00	94.48	3.00
	16	81.60	1.00	93.25	1.75	91.41	1.50	92.64	2.25	97.55	4.50	96.34	3.25

Table 7.24 The best correct classification result from FCOM on the NewBarkTex validation set.

Color space	C	Feature set											
		FzCM1		FzCM2		FzCM3		FzCM4		FzCM5		FzCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	76.83	2.00	92.02	6.75	88.41	5.00	79.75	6.00	92.02	11.00	91.41	6.75
	8	80.98	3.25	92.64	7.00	87.73	4.00	81.10	8.50	93.25	12.75	92.64	11.00
	16	84.66	6.50	92.68	20.00	89.57	10.25	84.05	12.75	94.48	18.25	93.25	17.75
HSV	4	82.21	2.75	93.87	6.00	90.80	4.75	84.66	5.00	93.25	8.25	92.02	8.00
	8	85.28	3.50	97.55	9.25	91.46	10.25	87.20	10.25	95.10	20.00	93.25	20.00
	16	87.73	7.00	94.48	12.25	91.46	8.75	90.85	16.25	92.68	19.00	93.87	20.00

Table 7.25 The best correct classification result from FCLCOM on the NewBarkTex validation set.

Color space	C	Feature set											
		FzCLCM1		FzCLCM2		FzCLCM3		FzCLCM4		FzCLCM5		FzCLCM6	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	72.39	2.00	88.96	3.50	82.21	2.25	72.39	3.50	88.34	6.75	88.34	5.25
	8	74.85	2.00	88.96	3.00	85.89	4.75	74.85	5.00	88.96	6.75	88.96	8.25
	16	72.39	3.00	88.34	7.00	84.66	5.50	74.23	7.00	90.80	16.75	88.96	12.25
HSV	4	68.71	1.00	82.82	2.00	79.75	2.25	68.10	2.00	81.60	7.75	80.37	4.25
	8	65.64	1.50	81.60	3.00	75.61	4.50	75.00	5.50	83.54	11.00	80.37	6.50
	16	67.07	5.50	80.49	5.75	75.46	4.50	75.61	11.75	83.54	17.25	81.60	11.25

Table 7.26 The best correct classification result from CLCM on the NewBarkTex validation set.

Color space	N_g	Feature set							
		CLCM1		CLCM2		CLCM3		CLCM4	
		Accu	σ	Accu	σ	Accu	σ	Accu	σ
RGB	4	88.96	1.50	75.00	0.75	88.41	2.50	83.44	2.50
	8	93.87	1.75	85.28	1.25	94.48	2.75	89.57	3.00
	16	96.32	2.25	87.73	1.25	94.48	3.50	92.64	4.00
HSV	4	88.34	2.25	73.01	0.50	88.96	3.25	79.14	1.25
	8	93.25	1.75	77.30	0.75	94.48	5.00	85.89	2.75
	16	95.71	2.00	83.44	0.75	95.09	5.00	85.89	2.25

Table 7.27 The summary of the best validation set classification results on the NewBarkTex data set.

Method	**Color space**	**Color levels**	**Accuracy (%)**	**RBF σ**	**Feature set**
GLCM	HSV	16	97.55	4.50	GLCM2
CLCM	RGB	16	96.32	2.25	CLCM1
FCOM	HSV	8	97.55	9.25	FzCM2
FCLCOM	RGB	16	90.80	16.75	FzCLCM5

From the summary of the best validation set classification results on this data set, texture features from GLCM and FCOM provided the best recognition rate but FCOM provided lower color levels. The color space in this case was HSV while FCLCOM and CLCM provided the best results on RGB color space. Again, the reason was that the features were extracted from GLCM and FCOM by combining each color channel while all of the color information were extracted using FCLCOM and CLCM methods. In addition, images were equal in tonal color but smoothness was dissimilar.

5.3 Summary

In this chapter, we introduced the system for color texture classification. The experiments were evaluated on the Outex, USPTex, Biomass, MondialMarmi, and NewBarkTex data sets. For Outex and USPTex color benchmark data sets, the images in these data sets were correlated. Biomass, MondialMarmi, and NewBarkTex were the real world application color texture data sets. They were collected from the same type of textures from Outex and USPTex. The best validation classification results were summarized showed in table 7.28. We found that the features from our proposed FCOM provided a better result. RGB color space was suitable for extracting features with low variety of colors while HSV color space was advised in high color variation. Color levels were selected from the distribution of colors in images. The lower color distribution uses the lower color levels, while the higher color distribution uses the higher color levels. To improve the recognition rate, the distance of a pixel pair is optimized if necessary.

Table 7.28 The summary of the best validation color texture classification results.

Data set	**Method**	**Color space**	*Ng or C*	**Accuracy (%)**	**RBF σ**	**Feature set**
Outex	GLCM	RGB	16	97.06	3.00	GLCM5
USPTex	FCOM	HSV	16	97.03	15.75	FzCM6
Biomass	All	RGB	4	100.00	0.50, 0.75, 1.00, 0.75	GLCM1, CLCM1, FzCM1, FzCLCM1
MondialMarmi	All	RGB	4	100.00	0.25, 0.25, 1.00, 0.50	GLCM1, CLCM1, FzCM1, FzCLCM1
NewBarkTex	FCOM	HSV	8	97.55	9.25	FzCM2