Colour classification method for recycled melange fabrics

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Colour Classification Method for Recycled Melange Fabrics

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Abstract: Classification of wasted woollen textiles on the basis of their colour is a basic approach for the supply of a raw material which does not involve the cost of the colouring process. Colour classification is a very difficult task, especially when a fabric is composed by differently coloured fibre (melange fabric). Many systems have been developed in the last years for colour classification of textiles. Unfortunately such colour classification systems are not able to correctly classify melange fabrics. In the present work a method for real-time classification of melange colour woollen fabrics is proposed. The provided approach, that is suitable also for classifying solid colour fabrics, integrates a Machine Vision (MV) system, able to acquire high resolution images, with a clustering algorithm capable of mapping the colour pixel of fabric images into a series of colour classes. The proposed system provides a colour classification with a misclassification less than 10% when compared with the classification resulting from a panel of expert human operators. A comparison between the proposed method and some tools stated in scientific literature is also afforded.

Key words: Recycling, machine vision, mapping, melange, textiles

INTRODUCTION

Every year about 1 million tons of textiles are thrown away leaving a pollution footprint (Claudio, 2007). A wide range of products may be obtained by applying recycling techniques since the final product is, often, obtained using only one raw material. Recycling involves collecting both post-industrial cloths left over from fabric and garment manufacture and post-consumer waste (like used clothes and other household textiles). These fabrics are sorted according to type, colour and grade and then shredded into fibres that can be mixed with new ones and then spun for weaving or knitting (El-Nouby *et al*., 2005). Accordingly, recycling is a basic approach for the supply of a raw material which does not involve the cost of the colouring process, saves energy and reduces pollution resulting from the dyeing and colour fixing processes applied to new, raw cloth. Moreover, recycling saves water, which is used in large quantity to wash and treat raw cloths (Yousif *et al*., 2006). In Italy the wool industry produces a volume of approximately 55.000 ton year^{-1}, 50% of which are fashioned in the textile district of the city of Prato, in central Italy.

Prato is mainly a woven textile district: About 72% of these 50,000 employees are engaged in textile production, 16% in apparel and 12% in knitwear (Owen and Jones, 2003). The proportion of textile wastes reused or recycled annually in the district was, in 2000, around 25% (Levy and Dellorco, 2000) so it is estimated, now a rate of 26-27%. As a consequence in the last decades a series of methods for textile recycling have been devised (Abreu and Silva, 2006). The first step for companies performing textile recycling consists in classifying the clothes on the basis of their composition and colour since this one is one of the most fundamental aspects of textiles which contribute greatly to the overall visual effect of a finished fabric.

Referring only to wool (and wool-based) textiles, the companies performing recycling classifies wasted fabrics into colour classes according to a catalogue of available colours. The company's operators required to classify the clothes (called pickers), have to be aware of the way a wasted cloth can be categorized into one of the colours of their catalogue. Since any of the colours of a wasted cloth exactly matches a colour class, significantly different coloured clothes may be grouped together in the same colour class. Furthermore, when a Melange fabric, i.e., a fabric composed by a number of fibres with at least two different colours (Mahmood *et al*., 2009), colour classification becomes a very tricky task, since the company experts have to classify it in the colour class that is mostly similar to the predominant colour of the fabric. As a consequence the selection method relies heavily on the judgment of the operators and consequently may vary remarkably depending on the operator's skill, colour perception and tiredness. Moreover, this method is characterised by a low and non-constant productivity.

Several different methods for classifying textile fabrics on the basis of their colour have been devised in the last years. For instance the use of colour cameras (Barnard *et al.*, 2000), adaptive histograms (Pérez and Millàn, 1997) and colour histogram (Luo, 2006). Fuzzy clustering and fuzzy logic have been successfully applied for classifying colours in cotton textiles (Xu, 2003). An objective identification and classification of pigmented fibres in cashmere has been performed by Su *et al.* (2003).

A system for classifying the colour aspect of textured surfaces having a nearly constant hue (such as wooden boards, textiles, wallpaper etc.) has been proposed by Daul *et al.* (2000).

Recently some approaches based on the combination of Spectrophotometry and Artificial Neural Networks have been proposed in order to confront this issue (Furferi and Governi, 2008). In such an approach the colorimetric control is mainly performed using a calibrated reflectance spectrophotometer thus allowing an accurate measurement of the spectrum of a woollen yarn. Being the area of the spectrophotometer acquisition sensor very small (about 20 mm^2) this tool is not able to properly classify melange fabrics since a single spectrophotometric reading is not suitable for discriminating the two (or more) colours of the fibres composing the fabric.

With regards to melange fabrics, a number of researches can be directly applied or derived to cluster the colours composing it (Kuo and Kao, 2007) even if a few studies are strictly related to the colour measurement of melange textiles (Furferi and Carfagni, 2007).

In order to reduce both the process time and the subjectivity of the colour classification, a method for real-time classification of melange and solid colour woollen fabrics is proposed. The approach integrates a Machine Vision (MV) system, able to acquire high resolution images, with a colour clustering algorithm able to map the colour pixel of fabric images into a series of colour classes.

The proposed system provides a colour classification with a reliability index equal to 0.91 thus providing a classification error within 9% compared to the picker's selection criteria.

MATERIALS AND METHODS

In order to implement a method able to perform a real-time colour classification of recycling melange and solid colour woollen fabrics the following tasks have been carried out:

- MV system development
- Data collection
- Image acquisition
- Colour clustering
- Colour classification

This study was carried out from 2008 to 2010

MV system development: The devised colour classification system consists of a sealed cabin hosting a high resolution uEye UI-1480 camera QSXGA (2560x1920 pixel 2) provided with a ½ inches CMOS sensor and with a frame rate of 6 fps. The camera is rigidly attached to a support and positioned upright to the plane where the fabric to be classified in terms of colour is disposed. The camera is connected to a PC by means of a graphical user interface (GUI) appositely developed in Matlab® environment. The acquisition is performed by using an ActiveX Twain controller. The cabin hosts also a CIE Standard Illuminant D65 lamp (that corresponds roughly to a midday sun in Western/Northern Europe with a U.V. spectrum component and a colour temperature of 6500K). The illumination system has been chosen in order to perform a repeatable and controlled acquisition able to preserve the colours of each fabric to be classified.

Data collection: A catalogue of 96 available colours provided by an important company operating in Prato (Italy) has been used in this work. In detail, the catalogue consists of a set of 96 differently coloured wool samples, demonstrating all the colours available to the customer. Each sample of the catalogue represents a colour class. In Fig. 1 some of the colour classes of the catalogue are depicted.

The first step for developing the colour classification system is to select a number of fabrics to be classified.

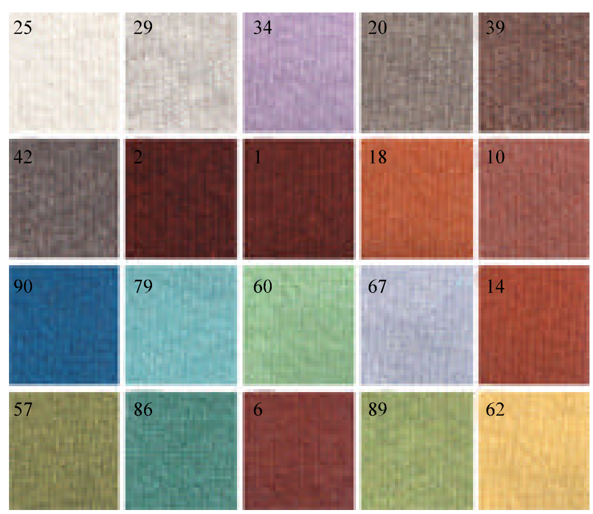

Fig. 1: Some samples of fabrics from the catalogue used for the present work. Each number onto the images represents the colour class

This operation has been performed by the company experts. The selected fabrics have been classified into one of the 96 colour classes by a panel of 5 company pickers. It is important to remark that this classification is not error free since the mean classification error of visual inspection is about 5%. In order to have a sufficient variety of samples 15 different cloths for each class are collected. Accordingly the database results to be made of 1440 fabrics classified by the company staff. Among them, 1000 fabric are composed by fibres of two colours (melange fabrics). Some results of the classification performed by the pickers are provided in Table 1.

Image acquisition: Using the MV system previously described, an image of each of the 1440 fabrics has been acquired in full resolution. Moreover, the 96 colour samples composing the catalogue, i.e., the colour classes, are also acquired by using the same MV system. The result consists of a database of 1440 images each one representing a fabric to be classified in terms of colour and 96 images depicting the colour classes of the catalogue. As already stated, all the images are acquired under controlled environment and their size is m × n with n = 1…2560 and m = 1…1920.

Colour clustering: Each acquired image can be represented in the RGB three dimensional colour space as shown in Fig. 2, where each pixel is mapped by the triplet of its RGB values. As depicted in such a Fig. 2, related to fabric with Id. = 100 the fabric colour is represented by a multiplicity of RGB values (even if they are similar in solid colours) especially in case of melange fabrics. For this reason it is important to perform a colour clustering of the images in order to reduce the RGB values into a restricted number of clusters. For each of the 96 colours composing the catalogue, it is possible to evaluate the mean value of the three channels R, G and B. The result of this procedure is to build a colour map (Table 2), also called Look-Up Table (LUT), of the 96 colour classes in order to perform the colour clustering as described below.

In Fig. 3, the RGB values for the 96 colour classes are plotted in a three dimensional colour space whose axis are the R, G and B channels.

Once created a colour map, it is possible to convert any of the 1440 RGB images representing a fabric to be classified in terms of colour to an indexed image (Floyd and Steinberg, 1975). The algorithm used for indexing simple detects, for each pixel in the processed RGB image, the closest colour of the map, in terms of Euclidean distance and assigns it to the correspondent pixel in the indexed image.

In Fig. 4 an example of result of indexing, referred to two fabric (Id. = 100 and Id. = 1040 one melange and the other in solid colour) is depicted.

Table 1: Classification into colour classes of some of the 1440 fabrics used for experimenting the proposed method

Fabric Id.	Melange/ Solid colour	Accepted/Discarded	Colour class provided by the pickers
1	Melange	Accepted	24
20	Melange	Accepted	18
40	Melange	Accepted	67
60	Melange	Accepted	59
80	Melange	Accepted	23
100	Melange	Accepted	16
200	Melange	Accepted	54
350	Melange	Discarded	-
400	Melange	Accepted	49
550	Melange	Accepted	62
560	Melange	Discarded	-
600	Melange	Accepted	2
700	Melange	Accepted	7
1000	Melange	Accepted	94
1001	Solid Colour	Accepted	49
1020	Solid Colour	Accepted	37
1040	Solid Colour	Accepted	61
1100	Solid Colour	Discarded	-
1200	Solid Colour	Accepted	56
1400	Solid Colour	Discarded	-

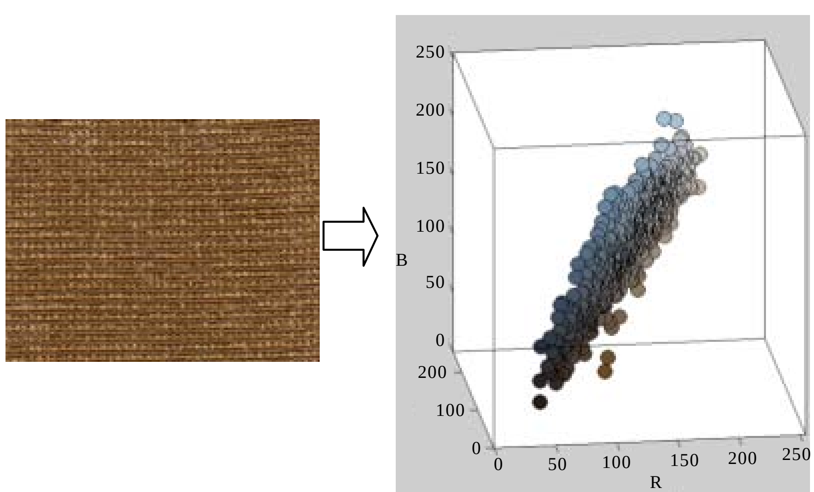

Fig. 2: Representation of an image (fabric with Id. 100) in the R, G and B colour space

Table 2: RGB mean values for the 96 colour classes (LUT)

Colour class	Mean values R	Mean values G	Mean values B	Colour class	Mean values R	Mean values G	Mean values B	Colour class	Mean values R	Mean values G	Mean values B
1	78.90	34.17	41.00	33	187.32	186.75	185.03	65	194.15	201.58	171.37
2	91.87	39.10	44.13	34	169.28	168.25	166.28	66	234.36	214.62	155.44
3	59.00	49.50	50.50	35	135.72	122.79	118.26	67	179.05	180.57	199.04
4	54.76	51.07	49.87	36	180.30	137.54	114.23	68	243.44	209.37	203.27
5	130.14	38.53	47.82	37	143.42	143.80	146.34	69	68.54	35.04	42.11
6	115.18	52.48	55.21	38	111.50	112.85	116.54	70	84.14	41.34	47.50
7	75.31	43.00	45.53	39	118.66	89.73	85.58	71	59.37	51.77	54.81
8	58.40	52.96	53.33	40	129.09	103.20	91.87	72	55.70	54.57	56.86
9	157.52	41.34	50.58	41	85.45	86.55	91.42	73	124.95	41.74	51.53
10	146.96	85.88	84.22	42	65.46	66.58	72.22	74	116.85	55.28	59.31
11	119.49	49.70	51.94	43	106.64	95.45	95.75	75	79.78	47.75	51.30
12	89.83	75.30	65.56	44	88.42	72.31	69.92	76	62.26	57.28	58.65
13	162.05	49.04	52.76	45	50.47	51.20	56.76	77	181.16	194.31	181.38
14	147.86	58.57	50.63	46	44.03	44.81	51.60	78	180.73	204.60	200.33
15	159.49	107.55	82.88	47	68.88	63.60	65.32	79	159.14	174.98	193.41
16	118.72	101.43	82.29	48	57.32	51.29	56.48	80	173.40	183.00	193.72
17	188.26	75.56	77.11	49	60.74	63.32	64.14	81	116.66	126.84	115.26
18	171.93	81.75	63.02	50	73.29	67.78	63.79	82	133.67	183.80	184.63
19	167.09	122.40	91.59	51	77.88	65.02	91.59	83	144.38	167.14	168.30
20	135.72	122.79	118.26	52	74.45	52.22	63.55	84	125.71	145.55	166.41
21	189.17	144.17	129.79	53	78.38	78.47	69.52	85	84.08	97.45	91.62
22	189.82	152.03	124.44	54	116.90	102.43	75.22	86	95.02	138.33	125.51
23	185.39	164.98	134.00	55	132.04	74.15	113.55	87	104.27	125.11	132.15
24	182.18	163.26	140.65	56	175.70	59.48	78.18	88	95.09	121.19	158.54
25	236.23	230.79	221.98	57	130.93	130.65	84.83	89	154.69	165.90	107.37
26	228.28	219.98	208.01	58	166.55	152.48	114.54	90	57.15	95.45	135.44
27	204.07	197.84	192.60	59	155.66	77.39	113.69	91	59.17	63.25	78.33
28	207.02	193.04	184.53	60	203.97	92.88	121.43	92	45.93	56.95	56.77
29	205.61	204.02	200.04	61	222.17	149.31	176.12	93	54.27	68.93	79.18
30	202.66	198.91	193.92	62	205.09	160.44	107.68	94	57.62	62.75	76.38
31	175.24	164.26	157.54	63	136.01	119.53	157.26	95	46.86	49.25	60.73
32	172.03	142.68	129.66	64	223.27	150.23	176.47	96	77.06	93.46	73.35

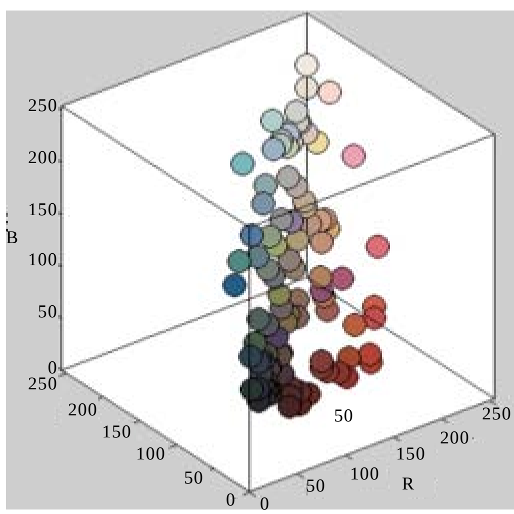

Fig. 3: RGB values for the 96 colour classes

As widely known, an indexed image does not explicitly contain any colour information. Its pixel values represent indices into the defined LUT. Colours are applied by using these indices to look up the corresponding RGB triplet in the LUT. In other words, each pixel p(n, m) of acquired images, is mapped to a value c(n, m) where, c is an integer varying in the range [1… 96].

Accordingly, by using indexed images it is possible to evaluate the number of pixels associated to each colour used in the colour map; assuming for instance that an

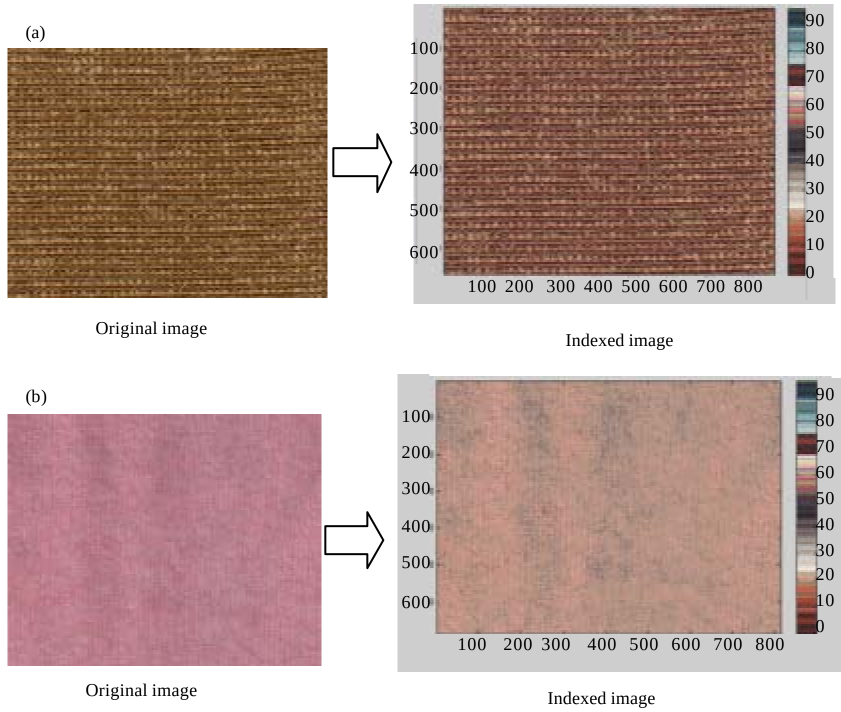

Fig. 4: Indexing of fabrics with Id. =100 (melange fabric) and Id. = 1040 (solid colour fabric) (a) Melange fabric and (b) Solid color fabric

image has been clustered into a set of k of the 96 colours of the catalogue, it is possible to derive the number of pixel p_k of image that have been clustered into kth colour class as follows:

$$p_k = \frac{\sum_{n=1,m=1}^{n=2560,m=1920} [c(n,m)=k]}{k} \tag{1}$$

In other words the number of pixels that have been clustered into a colour class k is equal to the number of pixels of indexed image that assume the value c = k.

Moreover it is possible to define the membership to a colour class as the percentage $P_{k\%}$ of an image that have been clustered into a colour class k as follows:

$$P_{k\%} = \frac{p_k}{n \cdot m} \tag{2}$$

Referring to the two fabrics of Fig. 4a and b the results of colour clustering are depicted in Fig. 5a and b, where the plot of the RGB values of the indexed images is also shown; in such a figure the coloured disk dimensions are proportional to the number of pixels.

Colour classification: A first criterion for classifying the fabrics into one of the 96 colour classes is to deem that the maximum value of $P_{k\%}$ clearly states the most probable colour class. In other words the greater is the membership value $P_{k\%}$ the greater is the number of pixel whose RGB triplet is similar to the one of the correspondent colour class.

In the explanatory example of fabrics with Id. = 100 and Id. = 1040, the maximum values of the membership is provided by, respectively, colour class 16 (melange fabric) and 61 (solid colour fabric) as described in Fig. 6.

As previously described, this criterion in classifying the recycled fabrics is based on the RGB colour distance between the fabric to be recycled and the colour class of the catalogue. In the textile practice, however, the Britain standard called CMC distance is adopted for comparing fabrics in terms of colour. The CMC is not a colour space but rather a tolerancing system based on CIELCH and provides better agreement between visual assessment and measured colour difference. CMC tolerancing was developed by the Colour Measurement Committee of the Society of Dyers and Colourists in Great Britain and became public domain in 1988.

With the aim of providing a criterion for colour classification that bring into play the CMC colour distance, a colour space transform is necessary.

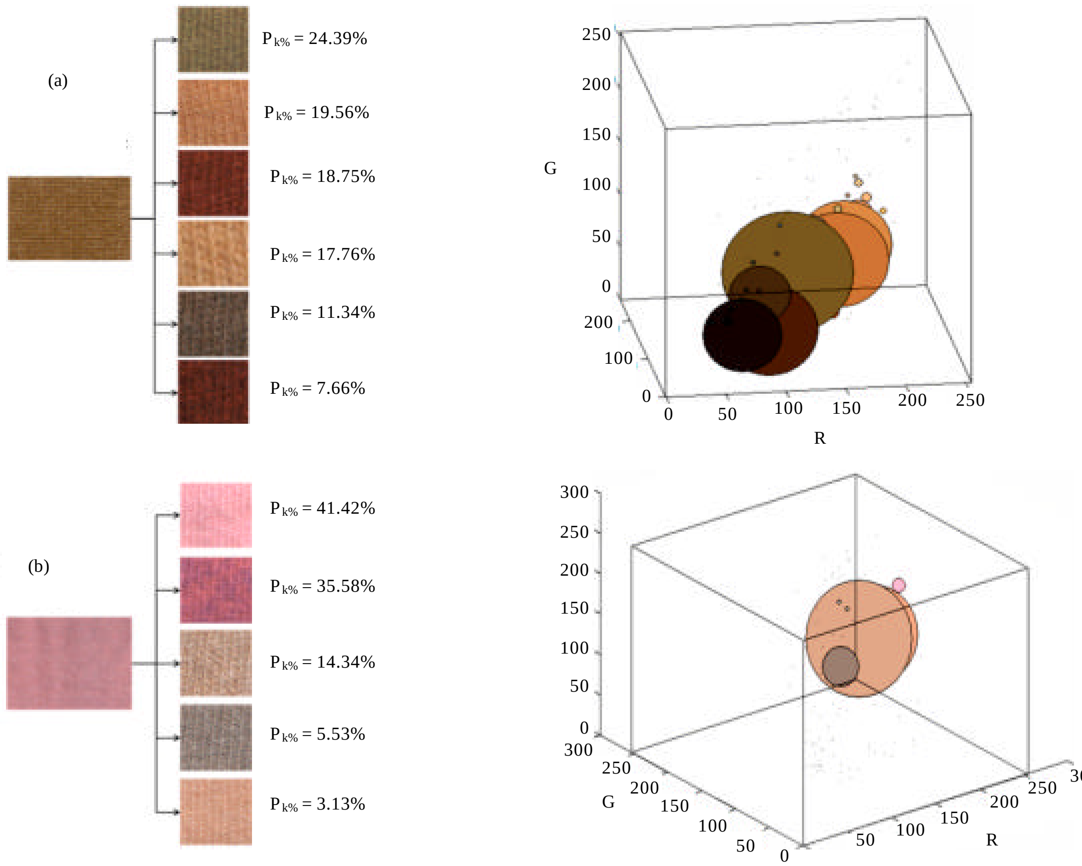

Fig. 5: Results of colour clustering for fabrics with Id. = 100 and Id. [illegible]; the plot of the RGB values of the indexed images is also shown; the coloured disk dimensions are proportional to the number of pixels (a) Melange fabric and (b) Solid color fabric

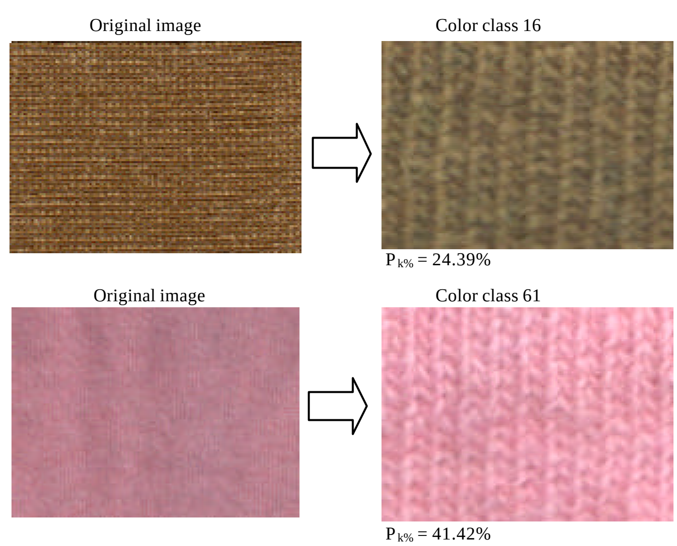

Fig. 6: Maximum values of the membership

In particular the following tasks have been performed:

Task 1: Conversion of the RGB values of all the 96 colour classes to the CIELCH colour space. First, a conversion from the RGB space to the tristimulus values CIE XYZ (Kim and Nobbs, 1997), under the illuminant D65, is performed. Second, the knowledge of the XYZ values, allows the colour transformation in the CIELAB space simply using the XYZ to CIELAB relations (Williams, 2006) thus obtaining the L, a* and b* values. Finally, from the CIELAB colour space it is possible to evaluate 96 vectors W_k, with k = 1...96, containing the CIELCH values for all the 96 colour classes:

$$W_k = [L^*_k, C^*_k, H°_k]$$

Where:

$$\begin{cases} C^*_k = \sqrt{(a^*_k)^2 + (b^*_k)^2} \\ H^°_k = \tan\left(\frac{b^*_k}{a^*_k}\right) \end{cases} \quad (3)$$

Task 2: Evaluation of the mean values of R, G and B for an image of the fabric to be classified in terms of colour and conversion of such mean values of R, G and B into CIELCH colour space according to the procedure stated at task 1. The result is, for a generic image I a vector V containing a triplet of L*, C* and H° values:

$$V = [L^*_I, C^*_I, H°_I]$$

Task 3: Evaluation of the CMC colour distances between the vector V and all the vectors W_k, The CMC calculation mathematically defines an ellipsoid around the standard colour with semi-axis lS_l, cS_c and S_h corresponding, respectively, to lightness, chroma and hue. The ellipsoid represents the volume of acceptable colour and automatically varies in size and shape depending on the position of the colour in colour space.
The CMC distances between vector V and vectors W_k, CMC_k, are evaluated according to the following equation:

$$CMC_k = \sqrt{\left(\frac{L^*_I - L^*_k}{lS_l}\right)^2 + \left(\frac{C^*_I - C^*_k}{cS_c}\right)^2 + \left(\frac{H^°_I - H^°_k}{S_h}\right)^2} \quad (4)$$

Task 4: In colour classification, Once the CMC distances between vector V and vectors W_k are evaluated, it is possible to classify the fabrics into one of the colour classes provided by the catalogue according to the following statements:

- The fabric is classified into the colour class k corresponding to the greater value of $P_{k\%}$ only if the correspondent CMC_k colour distance is less than a threshold value. In the present work such threshold value is set to 10
- The fabric may also be classified also into colour class k corresponding to the second greater value of $P_{k\%}$ if the corresponding CMC_k colour distance is less than the set threshold
- The fabric is discarded in any other case. Considering, for instance, the fabric with Id. = 1040, the results of colour clustering are the ones listed in Table 3. As depicted in Fig. 7 both colour classes 61 and 59 presents a CMC distance less than the set threshold. Since the 41.42% of image pixels have been classified into cluster 61, such a colour class is chosen as the most probable

Table 3: Results of colour clustering for fabric with Id. = 1040

Results	Image of fabric Id. 1040	Cluster 1 (colour class 61)	Cluster 2 (colour class 59)	Cluster 3 (colour class 32)	Cluster 4 (colour class 35)	Cluster 4 (colour class 20)
Cluster (%)	-	41.42	35.58	14.34	5.53	3.13
R	171.22	222.17	155.66	172.03	135.72	135.72
G	116.77	149.31	77.39	142.68	122.79	122.79
B	136.71	176.12	113.69	129.66	118.26	118.26
L*	55.226	69.677	43.660	61.590	52.552	52.552
a*	24.653	31.486	37.203	9.280	4.376	4.376
b*	-2.783	-3.500	-6.270	10.460	3.708	3.708
C*	24.810	31.680	37.728	13.983	5.736	5.736
H°	353.559	353.657	350.434	48.421	40.276	40.276
LAB distance	-	16.00	17.42	21.26	21.45	20.89
CMC distance	-	6.82	7.12	66.37	67.63	68.97

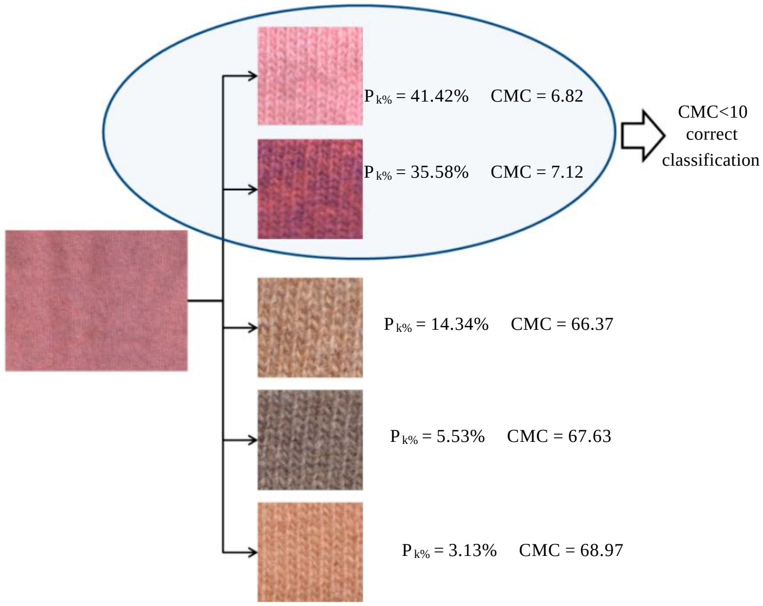

Fig. 7: Classification into two colour classes (both presenting a CMC distance less than the set threshold) of the fabric with Id. 1040

RESULTS

The classification method described in the present work has been validated using the set of 1440 differently coloured fabrics to be recycled split in all the 96 colour classes. In order to measure the performance of the classification method, a comparison between the classification performed by the pickers and the one allowed by the proposed method has been carried out. In detail a colour classification reliability index τ, given by the following equation, is adopted:

$$\tau = \frac{T_{CC} + T_D + 0.5T_{CF}}{T_C} \quad (5)$$

where, T_{CC} is the total number of the fabrics correctly classified (i.e., the pickers and the proposed method classify the fabric in the same colour class.

T_D is the number of the fabrics discarded by both the pickers and the provided method.

T_{CF} is the number of fabrics classified with a CMC distance less than the threshold into a colour class different from the one chosen by the pickers (so a weight of 0.5 is used for evaluating the system performance).

T_C is the total number of fabrics to be classified in terms of colour.

The definition of such an index is crucial for two kinds of reasons: first the index allows the measurement of the performance of the developed method and second it allows a comparison between the proposed method and other systems provided by literature.

Referring to the fabrics listed in Table 1, the colour classification method results are provided in Table 4. The fabrics with Id. = 80 and 600 have been classified into a colour class that is close but different from the one provided by the pickers. The fabric with Id. = 100, i.e., the melange fabric is characterized by a CMC distance greater than the threshold value; accordingly it is discarded by the colour classification method (please note that this is the reason why it has been chosen as an illustrative example).

Referring to the whole database of 1440 images, the results may be aggregated in terms of colour classes as described in Table 5.

The mean value of τ for the whole set of fabrics is equal to 0.91 with a variance of 0.0005. This means that with regards to the whole set of images, the mean error in classification is equal to 9% with a maximum error of 12% for some colour classes. Such a result proves that the proposed colour classification method respects the objectives of this work that was to state a method for performing a reliable classification of melange and solid colour fabrics. It is important to remark that the Pickers' classification is based on a subjective color perception that changes over time thus increasing the number of classification errors. For this reason the compared results provided in the Table 5 have to be considered as an excellent result since it is probable, even if unlikable, that

Table 4: Results of the colour classification method for 20 of the 1440 tested fabrics

Fabric Id.	Melange/ Solid colour	Accepted/ Discarded	Colour class provided by the pickers	Colour class provided by the colour classification method	CMC Distance	Cluster (%)
1	Melange	Accepted	24	24	8.21	56.21
20	Melange	Accepted	18	18	9.23	49.34
40	Melange	Accepted	67	67	5.67	53.32
60	Melange	Accepted	59	59	7.87	39.92
80	Melange	Accepted	23	22 (or 23)	6.78 (7.23)	51.28 (32.45%)
100	Melange	Accepted	16	Discarded (the cluster with high % is 16)	11.34	24.39
200	Melange	Accepted	54	54	7.58	49.42
350	Melange	Discarded	-	Discarded (the cluster with high % is 34)	14.57	22.76
400	Melange	Accepted	49	49	8.32	42.87
550	Melange	Accepted	62	62	9.76	39.52
560	Melange	Discarded	-	Discarded (the cluster with high % is 54)	10.82	44.65
600	Melange	Accepted	2	1 (or 2)	4.32 (5.67)	36.67 (34.98)
700	Melange	Accepted	7	7	5.78	56.73
1000	Melange	Accepted	94	94	8.92	45.60
1001	Solid Colour	Accepted	49	49	6.02	64.91
1020	Solid Colour	Accepted	37	37	5.53	34.76
1040	Solid Colour	Accepted	61	61 (or 59)	6.82 (7.12)	41.42 (35.58)
1100	Solid Colour	Discarded	-	Discarded (the cluster with high % is 9)	13.45	31.79
1200	Solid Colour	Accepted	56	56	6.31	44.66
1400	Solid Colour	Discarded	-	Discarded (the cluster with high % is 3)	14.56	53.98
				13 = 0.90		
				4		
				2		
				20		

Table 5: Results aggregated in terms of colour classes

Colour class	Value	Colour class	Value	Colour class	Value	Colour class	Value	Colour class	Value
1	0.89	21	0.95	41	0.90	61	0.87	81	0.91
2	0.93	22	0.89	42	0.89	62	0.91	82	0.93
3	0.91	23	0.90	43	0.91	63	0.93	83	0.91
4	0.94	24	0.89	44	0.93	64	0.93	84	0.89
5	0.92	25	0.94	45	0.91	65	0.94	85	0.88
6	0.91	26	0.94	46	0.93	66	0.88	86	0.89
7	0.90	27	0.95	47	0.95	67	0.93	87	0.88
8	0.89	28	0.93	48	0.90	68	0.91	88	0.90
9	0.88	29	0.92	49	0.90	69	0.91	89	0.92
10	0.93	30	0.97	50	0.92	70	0.89	90	0.92
11	0.96	31	0.95	51	0.89	71	0.89	91	0.91
12	0.96	32	0.89	52	0.88	72	0.88	92	0.90
13	0.94	33	0.92	53	0.89	73	0.93	93	0.92
14	0.92	34	0.93	54	0.91	74	0.90	94	0.89
15	0.89	35	0.90	55	0.89	75	0.94	95	0.88
16	0.92	36	0.94	56	0.88	76	0.92	96	0.93
17	0.93	37	0.91	57	0.89	77	0.95	Mean value	0.91
18	0.90	38	0.90	58	0.96	78	0.96	Variance	0.0005
19	0.89	39	0.90	59	0.89	79	0.93		
20	0.91	40	0.88	60	0.88	80	0.94		

the pickers sometimes classify the fabrics into a colour class that is, actually, considerably different from the colour of the fabric.

DISCUSSION

In the present study a method able to carry out a real-time colour classification of recycling melange and solid colour woollen fabrics has been described. The method integrates hardware + software in order to perform a colour classification.

The proposed method proves to be reliable and, in particular, is able to:

- Correctly clustering the images in terms of colour; this is a very important task for the colour classification task as stated by Lu (2007)
- Classify the new clothes with a reliability index averagely equal to 0.91
- Respect the selection criteria provided by human know-how
- Provide repeatable selections: several acquisitions have been performed for the same fabric and this leads to the same final classification
- Provide a real-time process: the images are processed (acquisition task + colour classification) in about 2 sec

Moreover, the system is highly automated and is capable of performing real-time classification since the only required operation is to place the fabric to be classified into the sealed cabin hosting the MV system.

A comparison between the results of the proposed method and the ones assessed by other methods provided in literature may be carried out considering that all the methods defines a dimensionless parameter (whose value is comprised in the range 0-1) for evaluating the performance of classification. Kukkonen *et al.* (2001) states that the correlation between measured and calculated spectral reflectances varies in the range 0.85-0.98 thus demonstrating the effectiveness of a Spectrophotometry-based approach. The same occurs in the work provided by Furferi and Governi (2008) where a reliability index is defined to assess the validity of the devised classification tool; the reliability index varies in the range 0.9-1 depending upon the colour family.

The colour classification reliability is also comparable to the ones obtained by Daul *et al.* (2000) in terms of errors in classification, since the mean error in classification is less than 10%.

Even if some other methods allow a more performing classification (in terms of reliability), the novelty of the proposed approach is that it is allowable for classifying melange fabrics. Referring to this kind of fabrics only a few works are known in literature, to the best of authors' knowledge. For instance, using dual-constant Kubelka-Munk theory (Kubelka, 1954), Che and Chen (2001) developed a method for colour matching of melange fibres with accuracy of 90%. Recently, Pan *et al.* (2010) perform an automatic inspection of solid colour fabric density by using the Hough Transform (Duda and Hart, 1972) and clearly states the possibility of adopting the provided method for examining melange fabrics also. Nonetheless a comparison may be performed between the proposed approach and some methods for colour classification of wood samples and of granite tiles. For instance in the work provided ny Lebow e*t al.* (1996) the misclassification rate for wood samples varies from 1.1 and 8%. In the work published by Kurmyshev *et al.* (2003) an accuracy varying in the range 87.6-97.1 % is assessed. Zhao (1996) obtains a 97% classification using a novel approach to the colour quantization.

Finally, in the research assessed by Lepistö *et al.* (2003), an average classification rate is defined. Such a rate varies in the range 84.4-98.2%. These results are in support with the ones provided by the present work.

By using the system described by Lu and Zhang (2006) it is possible to perform a colour classification capable of processing an image consisting of 640×480 at speeds of a maximum of 233.21 fps. In the present work the total consumption of time for colour classification is 2 sec; accordingly the proposed method is highly time-consuming with respect to some literature proposed methods. Nevertheless, the system proposed by authors, process images with higher resolution (2560×1920) and 2 sec is considered by the company experts an acceptable amount of time for colour classification.

Concluding, the proposed approach proposes a method that proves to be suitable for an efficient colour classification of melange and solid colour fabrics. Future works will be addressed to the development of a colour index for melange cloths.

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