Chromaticity Based Waste Paper Grade Identification

Mohammad Osiur Rahman, Aini Hussain, Noor Ezlin Ahmad Basri, Edgar Scavino, Hassan Basri, and Mahammad Abdul Hannan
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Malaysia

Abstract: *In recycling, waste papers are segregated into various grades as they are subjected to different recycling processes. Highly sorted paper streams facilitate high quality end products and save processing chemicals and energy. Automated paper sorting systems offer significant advantages over human inspection in terms of worker fatigue, throughput, speed, and accuracy. As a consequence, many automated mechanical and optical paper sorting methods have been developed to fill the paper sorting demand during 1932 to 2009. Because of inadequate throughput and some major drawbacks of mechanical paper sorting systems, the popularity of optical paper sorting systems has increased. The implementation of the previous methods, while being a step forward in the large-volume automated sorting technology, is still complex, expensive and sometimes offers limited reliability. This research attempts to develop a smart vision sensing system that is able to separate the different grades of paper using chromaticity. For constructing template database, hue and saturation of the paper object image in a selected area are considered. The paper grade is identified based on the maximum occurrence of a specific template in the paper object image. The classification success rates for white paper, old newsprint paper and old corrugated cardboard are 95%, 92% and 90%, respectively. Finally, the best result of the proposed method is compared with the results published in literature where waste paper grade identification systems were developed using other methods. The remarkable achievement obtained with the method is the accurate identification and dynamic sorting of all grades of papers using chromaticity, which is the best among the prevailing techniques of optical or electronic image based systems.*

Keywords: *Waste paper sorting, grades of paper, template matching.*

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1. Introduction

The primary challenge in the recycling of paper is to obtain raw material with the highest purity. In recycling, waste papers are segregated into various grades as they are subjected to different recycling processes. Highly sorted paper streams will facilitate high quality end product, and save processing chemicals and energy. The grade refers to the quality of a paper or pulp and is based on weight, color, usage, raw material, surface treatment, finish or a combination of these factors [17]. The waste paper sorting systems are classified into manual and automated systems. Automated paper sorting systems offer significant advantages over manual paper sorting systems in terms of human fatigue, throughput, speed, and accuracy. Automated paper sorting systems are classified into mechanical and optical systems. From 1932 to 2009, different mechanical [2, 7, 9, 11, 22, 24, 25], and optical [3, 5, 6, 10, 13], paper sorting methods have been developed to fill the demand of paper sorting. Mechanical paper sorting cannot achieve commercially viable throughputs and accuracy. The greatest advantages of optical paper sorting systems include the following: consistent and reliable production efficiency with a relatively high hit rate and purity; and low operational cost because of fewer manual workers on the production line.

The implementation of the previous methods, while being a step forward in the large-volume automated sorting technology, is still complex, expensive and sometimes offers limited reliability. All the systems segregate only two types of papers at one time. Moreover, no image processing or intelligent techniques are used to extract the features or characteristics from the paper objects. Manufacturers Standardization Society (MSS) and TiTech are the top two competitors for sensor-based paper sorting. They possess the technology and create partnerships with recyclers. MSS and TiTech utilize Near Infrared (NIR) spectroscopy technology and sell their systems in the United States, European, Australian, and Asian markets [16]. Pellenc, Bollegraaf, Lubo, and RedWave are also competitors in the paper submarket [16]. Finally, in industries, the paper sorting performance reaches 80% for both MSS and TiTech systems [23].

Recently, Rahman *et al.* [19, 20, 21] proposed three electronic image-based waste paper sorting techniques. The first technique [19] focused on the four points in the periphery of the paper object. Then, features surrounding those four points were extracted. Because the method did not consider texture information of the entire paper object, it may provide misleading information regarding the paper grade. The other two methods template matching [20] and co-occurrence features [21] achieved good paper grade identification success rate; however, in real time applications, both methods are slow because of the significant computing time. Moreover, the performance of the three electronic image-based vision systems is influenced by the lighting arrangement and to achieve the best performance the lighting consistency must be maintained during enrollment and identification phases.

Thus, the main goal of this study is to develop a smart vision sensing system that will be able to separate the different grades of paper using chromaticity. Hue (H) and Saturation (S) taken together are called chromaticity [8]. In this present system, the paper object image is divided into N-cells based on given window size [1, 18] as well as H and S values of the N-cells are considered to create respective candidate templates. Because the proposed method did not utilize intensity or brightness of the paper image, it overcomes the constrained to maintain the lighting consistency during enrollment and identification phases. Furthermore, the algorithm provides robust and fast result because the proposed method avoids the extra computational burden for preprocessing and only three features namely mode of hue, mean of saturation and mean of hue are used to identify the dominating color value of the paper object image.

2. Chromaticity Based Waste Paper Grade Identification System

Figure 1 illustrates the basic block diagram of the recyclable waste paper grade identification system using Chromaticity. The proposed system operates in two phases, i.e., enrollment and identification. In the subsection 2.1. to 2.4., it will be discussed all the processes of both enrollment and identification phases.

2.1. Image Acquisition

In this proposed system, 320×240 RGB images are captured from the inspection zone on the conveyor belt using a Logitech QuickCam Pro 4000 Web Camera [15]. To set the webcam properties, the brightness, contrast and saturation were adjusted to 50%, 50% and 100% of their respective scales. Because front lighting-directional-darkfield illumination is widely used in surface scratches or texture analysis [4, 18], this illumination technique is adopted for this experiment.

The conveyor belt speed is 14 feet per minute. The system processes 5 images per second. The real time scanning process produces two types of signals: Presence of an Object (PObj) and Absence of an Object (AObj). The system always performs a scanning operation to detect the presence of an object. The system captures the images from the inspection zone based on the two signals. If the AObj signal is detected after the PObj signal, then the system captures the image of the paper object from the inspection zone. This technique separates individual paper objects from the sequence of paper objects.

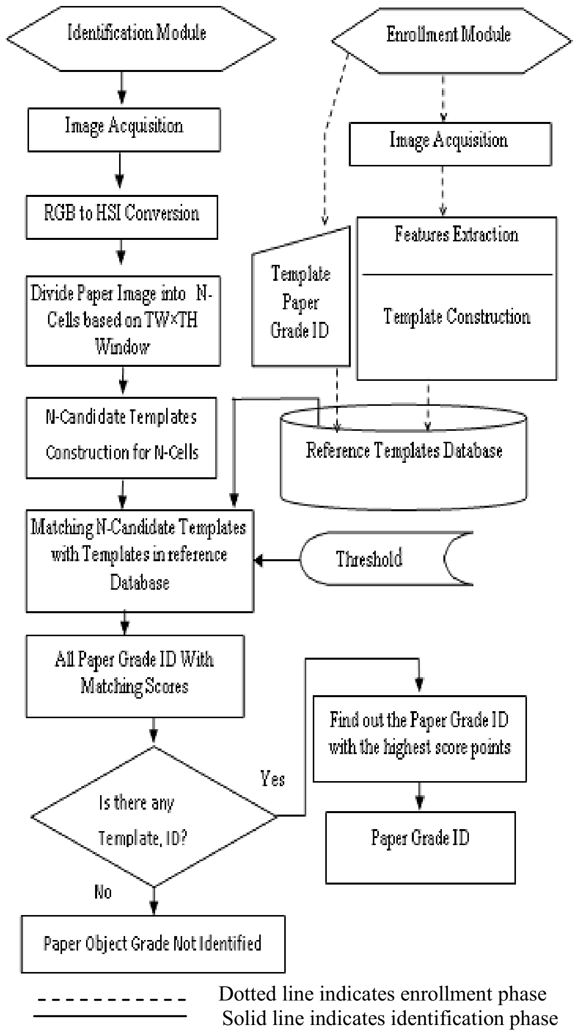


Figure 1. Block diagram of the paper grade identification system using chromaticity.

2.2. Features Extraction

The features extraction stage consists of RGB to HSI conversion, window-based paper object image subdivision, calculate the mode of the hue, mean of the hue, and mean of the saturation for all N-cells.

2.2.1. RGB to HSI Conversion

The paper object image consists of three components red, green and blue. For HSI color scale value, standard HSI scale transformation [8, 12, 18] is obtained from the original RGB image components using the following equations 1 and 2:

$$H = \begin{cases} \theta & if\, B \leq G \\ 360\text{-}\theta & if\, B > G \end{cases} \quad (1)$$

Where

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{\frac{1}{2}}} \right\}$$

$$S = \begin{cases} 0 & \textit{if} \max(R,G,B) = \min(R,G,B) \\ \dfrac{\max(R,G,B)-\min(R,G,B)}{\max(R,G,B)+\min(R,G,B)} & \text{if } L \le \dfrac{1}{2} \\ \dfrac{\max(R,G,B)-\min(R,G,B)}{2-\left(\max(R,G,B)+\min(R,G,B)\right)} & \text{if } L > \dfrac{1}{2} \end{cases} \quad (2)$$

Where

$$L = \frac{1}{2}(\max(R,G,B)+\min(R,G,B))$$

2.2.2. Window-Based Paper Image Subdivision and Features Extraction

After getting the value of window width, TW and window height, TH for the cell or window image, the paper image is divided into N-cells shown in Figure 2. The features mode of the hue, mean of the hue and mean of the saturation for each cell calculate using equations 3 to 5:

$$Mode = x \,\big|\, h(x) > h(i) : \forall i, 0 \le i, x < Z, i \ne x \quad (3)$$

Where:

h(x) stands for histogram of hue, is a one dimensional array that represents the number of pixels in the image with a hue level of *x*.
x stands for hue that can take any value between 0 and *Z-1*.
Z stands for the number of hue levels in the image which range is 0 to 239.

$$MeanHue = \frac{\sum_{m=1}^{TW}\sum_{n=1}^{TH} po\text{int}\, hue(m,n)}{pCell} \quad (4)$$

$$MeanSat = \frac{\sum_{m=1}^{TW}\sum_{n=1}^{TH} po\text{int}\, sat(m,n)}{pCell} \quad (5)$$

Where:

TW stands for the width of the cell or window.
TH stands for the height of the cell or window.
pCell stands for the total number of pixels in a cell or window.
MeanHue stands for the Mean of the Hue.
pointhue(*m, n*) return the hue value at point(*m, n*) in the cell.
MeanSat stands for the Mean of the saturation.
pointsat(*m, n*) return the saturation value at point(*m, n*) in the cell.

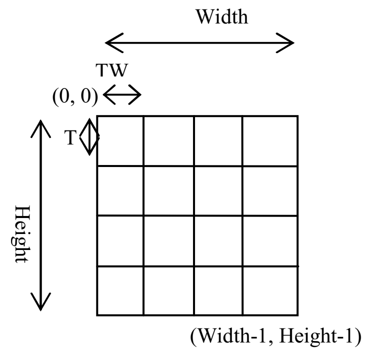


Figure 2. Template image and search image.

2.3. Template Construction

The template, *T* of the paper grade is:

$$T = \left\{PID,\ Mode_H,\ (Mean_H, Std_H),\ (Mean_S, Std_S)\right\} \quad (6)$$

Where:

PID=paper grade ID number.
$Mode_H$=mode of the hue.
$Mean_H$=Mean of the hue.
Std_H=Standard Deviation of the hue.
$Mean_S$=Mean of the saturation.
Std_S= Standard Deviation of the saturation.
Std_H and Std_S are used as a threshold value in matching process.

2.4. Matching and Decision

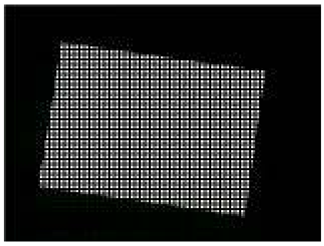
The main function of the matching process is to calculate the score of the reference templates. The matching process consists of three “if” conditions. Firstly, check whether the mode of the H for both candidate and reference templates are equal or not. Secondly, the distance of the mean S is less than the threshold value or not. Thirdly, the distance of the mean H is less than the threshold value or not. For any candidate template, if the reference template satisfied all of the three “if” conditions then the respective reference template gets one scored point and the above process is repeated for the next candidate template of the N-cell. On the other hand, if the reference template not satisfied all of the three “if” conditions then proceed with the next reference template and apply the three “if” conditions again and the processes are continued until the last of reference templates. In this way, the maximum occurrence of a specific reference template in the paper object image achieves the highest scored points. Finally, the template ID with the highest points is identified as the candidate paper object grade ID. In this experiment, total number of reference template is 124, and it is divided into three groups namely 0 to 42 ID for WP, 43 to 83 ID for ONP and 84 to 123 ID for OCC. The candidate paper grade name is identified based on the group of the paper grade ID.

3. Experimental Results and Discussion

In this experiment, the three types of waste papers White Paper (WP), Old News Paper (ONP) and Old Corrugated Cardboard (OCC) had taken because of their dominating role in waste papers. Figure 3 illustrated the images of the WP in both original and 5×5 window-based subdivided forms. Figure 4 illustrated the visualization of the waste paper objects in the chromaticity space. The success rates of the paper grade identification process for three major waste papers are shown in Table 1 and Figure 5. Four hundred and thirty paper samples for WP, four hundred paper samples for ONP and two hundred paper samples for OCC, in total 1030 paper samples are considered. The performance of this experiment is greatly influenced by window size. If the window size is decreased then the success rate of paper grade identification is increased. But the computational time is increased due to the number of cells in paper object image. The correct identification rate is calculated based on the percentage of the number of paper objects are classified into their respective paper grades. When the window size is 3×3 then achieved classification success rates are 95%, 88%, and 90% for WP, ONP, and OCC, respectively. For ONP the better classification rate 92% are achieved at window size 5×5 or 8×8. When the template size is 5×5 then the achieved average classification success rate is 90.97%. For the optimum performance in terms of classification success rate and computation time, the suggested window size is not greater than 8×8.

Finally, the best results of the proposed method is compared with the results published in literature where optical sensors or electronic image based waste paper grade identification systems were developed using other methods shown in Table 2. It is observed that the performance of the proposed system is the best among all existing systems except template matching [20]. The average maximum classification success rate of the template matching system is 94.67% [20]. On the other hand, the proposed system offered 91.067%. In real time implementation, the proposed system is more effective and convenient than the template matching technique because of the computational time, and lighting consistency. Firstly, in template matching, significant time is allocated for preprocessing, on the other hand, in proposed system there is no preprocessing. Secondly, the performance of the template matching method is dependent on the lighting consistency during enrollment and identification phases, the proposed system, on the other hand, is almost independent of the lighting condition since it uses only hue and saturation of the HSI color space. Thirdly, the 5×5 template consists of 25 pixels and for each pixel the RGB string length is 4 to 16, as such the RGB string length for 5×5 template is 100 to 400. As a result, there are 100 to 400 comparisons between one reference template and one cell image template, which makes the system inconvenient for real time implementation. Conversely, our proposed system, the template consists of only three values, namely mode of the H, mean of the S and mean of the H, which lead the system to provide fast result.

a) Original paper object image.



b) 5x5 Window-based subdivided image.

Figure 3. Illustrated the images of the WP in both original and 5×5 window-based subdivided forms.

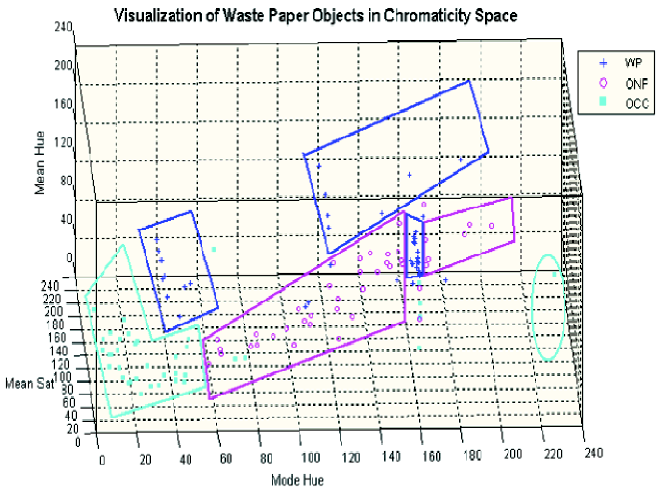


Figure 4. Visualization of waste paper objects in chromaticity space.

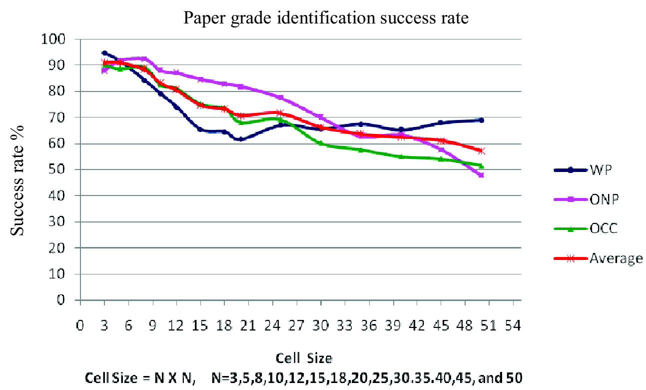


Figure 5. Paper grade identification success rates in different window-size.

Table 1. Classification successes rate for different window size.

Window Size	WP		ONP		OCC		Average Success Rate %
	No of Successes	Success Rate %	No of Successes	Success Rate %	No of Successes	Success Rate %	
3×3	407	95	351	88	180	90	91.06796117
5×5	393	91	367	92	177	89	90.97087379
8×8	362	84	369	92	178	89	88.25242718
10×10	340	79	352	88	165	83	83.2038835
12×12	318	74	348	87	162	81	80.38834951
15×15	281	65	338	85	150	75	74.66019417
18×18	277	64	331	83	147	74	73.30097087
20×20	265	62	327	82	136	68	70.67961165
25×25	288	67	310	78	138	69	71.45631068
30×30	282	66	280	70	120	60	66.21359223
35×35	290	67	251	63	115	58	63.68932039
40×40	280	65	253	63	110	55	62.42718447
45×45	292	68	230	58	108	54	61.16504854
50×50	296	69	191	48	103	52	57.2815534

Table 2. The results of the proposed method are compared with results published in literature.

Name of the Paper/ Patent/ Industries Standard	Techniques Applied for Identification	Types of Sensor	Features	Classification Success Rate
TiTech Systems [23]	Not Mentioned	NIR, CMYK sensor and color camera	Materials, shape, color , texture, and four color printing	80%
MSS Systems[23]	Not Mentioned	NIR, Color sensor, Gloss, and Lignin	The sensor measures the intensity of the material's fluorescence at a specific wavelength in the ultraviolet light.	80%
Recyclable Waste Paper Sorting Using Template Matching [20]	Template Matching	Logitech QuickCam Pro 4000 Web Camera	RGB String	94.67%
Segregating Recyclable Waste Papers Using Co-occurrence Features[21]	Rule based Classifier	Logitech QuickCam Pro 4000 Web Camera	Energy for the Co-occurrence matrices	90.67%
Mechatronic Design of a Waste Paper SortingSystem for Efficient Recycling [14]	Artificial Neural Network	Four Sensors: Lignin, Gloss, Stiffness, and Nikon D50 Digital SLR camera as a Color.	1. Average Lignin value. 2. Gloss meter reading. 3. Deflection in the upward direction. 4. Deflection in the downward direction. 5. color variance parameter I. 6. color variance parameter II.	36.6%
	Fuzzy Inference System Algorithm			90.4%
The proposed System	Window-based subdivision, and Distance Vector	Logitech QuickCam Pro 4000 Web Camera	Mode and Mean value of the Hue and saturation	91.067%

4. Conclusions

The main emphasis of this work is on the development of a new method for automated paper sorting system. The method described here mainly transforms the RGB pixels value to HSI color scale, window-based subdivision of the paper image into N-cells, construction of N-candidate template for N-cells, calculate the matching scores of reference templates for the N-cells paper image, and apply matching score and threshold value to identify the grade of the paper object. The proposed system performance for correct paper grade identification is more than 90% with estimated throughput of 18,000 paper objects per hour with a conveyor belt width of 18″. The weight of the throughput depends on the size and grade of the paper objects.

Another important idea that has been implemented in this proposed system is adaptability to new subcategories of the primary paper grades. The wide ranges of subcategories of paper grades are used to train the system to recognize new subcategories, and thus the system is scalable and able to provide robust decisions in paper grade identification. Besides, the proposed method did not utilize intensity or brightness of the paper image which overcome the constrained to maintain the lighting consistency during enrollment and identification phases. The most important point addressed in the proposed method is that the method, which uses computer vision, can be implemented easily to sort multiple grades of paper. Moreover, the algorithm provides robust and fast result because the proposed method avoids the extra computational burden for preprocessing and only three features mode of H, mean of H and mean of S are used to identify the dominating color value of the paper object image. Further work will focus on grading all type of papers and extended to other solid waste sorting, such as aluminum cans, glass etc. Some work on plastic bottle recycling is currently underway.

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Mohammad Osiur Rahman received MSc engineering in information and communication technology from BUET, Dhaka, Bangladesh in 2005 and BSc in electronics and computer science from SUST, Sylhet, Bangladesh in 1997. He is currently working toward the PhD degree in the Department of Electrical, Electronic and Systems Engineering, UKM, Malaysia. His research interests include DNA computing, biometrics, computer vision systems, and image processing.

Aini Hussain obtained her BSc, MSc and PhD in electrical engineering from Louisiana State University, USA; UMIST, England and Universiti Kebangsaan Malaysia, respectively. She is a professor at the Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia. Her research interests include pattern recognition, signal processing and computational intelligence.

Noor Ezlin Ahmad Basri received the Diploma in engineering, BE Hons in civil engineering, MSc tropical public health engineering and PhD in solid waste engineering from University College of Cape Breton, Canada in 1987, Technical University of Nova Scotia, Canada in 1992, University of Leeds, UK in 1994 and 2000, respectively. She is an associate professor at the Department of Civil and Structural Engineering, UKM, Malaysia. Her research interests include biological processes of solid waste treatment, expert system for solid waste management, water resources engineering, and wastewater treatment engineering.

Edgar Scavino received his MSc degree in nuclear engineering in 1994 from the Politecnico di Torino. He received the PhD in plasma physics in 2003 from the Ecole Polytechnique Fédérale de Lausanne. He is a senior lecturer in the Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia. His research topics are image analysis, pattern recognition and genetic algorithm applications on recyclable waste materials.

Hassan Basri obtained his BE in civil engineering from Tasmania University in 1982, and MSc in Engineering and PhD from University of Leeds, UK in 1988 and 1994, respectively. He is a professor of environmental engineering at the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Malaysia, and is currently the university Deputy Vice-Chancellor for academic and international affairs. His specialized in environmental applications of smart engineering systems and heads the environmental technology research group.

Mahammad Abdul Hannan received his BSc degree in electrical and electronic engineering from Chittagong University of Engineering and Technology, Bangladesh in 1990. MSc and PhD in Electrical, Electronic and Systems from UKM, Malaysia in 2003 and 2007, respectively. He is an associate professor in the Department of Electrical, Electronic and Systems Engineering, UKM, Malaysia. His research interests are in intelligent image and signal processing, RFID applications and FACTS and custom power devices.