Color classification of corn germplasm using computer vision

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ABSTRACT

A color classification program was developed for classifying the corn germplasm into seven different color groups based on kernel colors. This heuristic based rule supervised color classification program has an overall accuracy of 99%.

1. INTRODUCTION

Germplasm are the plant genetic resources or the raw materials required by plant breeders for the development of new and superior crop varieties. While collection and maintenance of germplasm plays a major role, more attention is being given to adequate evaluation of germplasm resources and dissemination of information on the accessions (samples) to the users. The National Plant Germplasm System (NPGS) of the United States now maintains over 400,000 accessions of germplasm in the form of seed and vegetatively propagated stocks.

The North Regional Plant Introduction Station located in Ames, Iowa primarily collects and maintains accessions of corn germplasm. During the characterization process of corn germplasm, various morphological descriptors i.e. maximum length, maximum width of ear-corn, number of rows of kernel, kernel width, kernel thickness, color of kernel, color of the cob, etc., are measured, evaluated, and recorded on an information sheet.

Errors in the measurement process may occur because of the variability among the operator's performance and the lack of consistency in describing the qualitative attributes such as color. Also, curators capture the ear-corn samples and store them in the form of photographic slides for future reference. This type of technique is not suitable for a long term storage because the color on the slides fades slowly with the time. Thus, the color information, obtained from the stored slides, may not provide correct color information about the ear of corn. Again, this station maintains over 8,000 accessions of corn germplasm. This

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germplasm. This amount of morphological information about the corn germplasm recorded on information sheets, thus become too cumbersome to be retrieved and disseminated to other users.

The advent of computer vision technology and other artificial intelligence have shown potential to remove some of the limitations of the presently followed characterization process. For example, computer vision technology has been proven to be very accurate and consistent for dimensional measurement processes, like length, width, area, and for description of qualitative properties like color, texture and brightness.

The advantages of color computer vision technology, with the capability to acquire and process color images, has been demonstrated by different research workers for performing quality control and grading of varieties of biological as well as agricultural products. For example: Color imaging system has been developed to detect defects in peaches[1] and to classify fungal damaged soybeans[9]. The color information of soybeans have been analyzed with a PC-based color vision system[7]. The color information combined with other derived features were used to evaluate the quality of soybeans[7].

In color image processing, the color information are generally represented by different color coordinates. The most common color coordinates used in the color image processing systems are RGB (red, green, and blue) and HSI (hue, saturation, and intensity).

Depending upon the application, the color features can also be transformed to other color coordinates. Huckel operator has been adopted for color edge detection[2]. This study revealed that the result obtained using Intensity (I) and normalized colors (r = R/I) and g = G/I) was better than that obtained using R, G, and B. The color information have been extracted from nine different color coordinates e.g. R (Red), G (Green), B (Blue), Y (luminanace), I and Q (Chrominance), H (Hue), S (Saturation), I (Intensity) for segmention of natural scenes[3].

A color imaging system has been developed for automatic inspection of Golden Delicious apples based on color, shape, size, and surface defects[8]. Based on the hue information of a digitized apple image, this system could discriminate apples for color with an accuracy of 100%.

In North Central Plant Introduction Station, Ames, IA, color is also an important feature for characterization of corn germplasm. Based on the color information of the kernel of the ears of corn, the ear-corns (accessions) are classified into seven different color groups as defined by International Board for Plant Genetic Resources. These color groups are red, yellow, light orange, orange, dark brown, white and light brown.

2. OBJECTIVE

The objective of this study was to develop suitable algorithm and software and to classify the ear-corn images into one of the seven color groups as defined by the International Board for Plant Genetic Resources.

3. EXPERIMENTAL PROCEDURE

The color images of ear-corns were acquired with a PC based color imaging system configured with a JVC color camera (TK810U) and a color frame grabber (DT2871)[6]. The images were captured in the HSI (Hue, Saturation, and Intensity) mode at a resolution of 480 rows x 512 columns x 8 bits/pixel[6]. To determine the color information of the object region (ear-corn), it was necessary to isolate the color information of the background region from the color image.

The image in the intensity buffer was smoothed using a 3 x 3 low pass filter[4]. The weight of each kernel of the low pass filter mask was 1. The image in the hue and saturation buffer was kept unchanged. A threshold value to discriminate the background region from the object region in the intensity buffer was selected using the modified Otsu's algorithm[5]. The locations of the background pixels were determined in the intensity buffer based on the selected threshold and their corresponding locations were mapped to the hue and saturation buffer. The hue and saturation values of the object region were used in all subsequent color information analysis.

3. 1. Development of color groups

In this vision system, color information of any object can be represented by a maximum of 256 levels in each of the hue and saturation buffers. These 256 different hue levels, however, do not represent 256 different colors to be perceived by human being. Instead, it was found from the preliminary study that each color group can be represented by a range of hue values. Again, at the time of this study, no literature was available for defining different ranges of hue values to represent different color groups. So, an experiment was conducted to find out the numeric ranges of hue values to define various color groups.

3.1.1. Numeric ranges of hue for various color groups

A computer program was developed to determine the numeric range of hue values for defining various color groups. The program created 256 non-overlapping and contiguous windows and displayed them on the computer screen as an image. Each window had a dimension of 60 rows and 16 columns (Figure 1). The intensity and saturation values for all the windows were 255 with the hue values ranging from 0 to 255. The 1st window and the 256th window, for example, had a hue value of 0 and 255 respectively. The hue values of other windows increased linearly from left to right and top to bottom (Figure 1). Based on the closeness of the visual color perception, ten different color groups and their respective numeric ranges of hues were determined (Table 1).

3.1.2. Numeric ranges of saturation for various color groups

In the saturation buffer, the lightness or brightness of any color is represented by 256 different levels of saturation values. A value of 0 represents the lightest and 255 represents the brightest saturation levels. Although the system has the capability of 256 different levels of representation of any color, it is not possible to distinguish all of them by visual perception. Again, at the time of this study, no literature was available to define the numeric ranges of saturation values for different distinct visually perceived color groups for any particular color. So, a computer program, similar to one described for hue levels, was developed to find the number of visually different color groups, and thus to determine the numeric range of the saturation levels for each color groups.

The computer program created 256 windows each with 480 rows x 2 columns and displayed them on the computer screen as an image. These 256 windows were contiguous and non-overlapping. The intensity values for each window was 255. The hue value was kept constant for all the windows to represent any particular color group and the saturation values ranged from 0 to 255. For example, the saturation level of the 1st window was 0 and that of the 256th window was 255. The saturation levels of the windows increased linearly from left to right (Figure 2).

The hue values were changed sequentially to represent different color groups. Based on the closeness of the observations of visual color perception, it was found that for each of the ten different color groups (Table 1), 3 color groups can be formed based on saturation levels. They were named as: 1) low-bright 2) medium-bright and 3) high-bright. For each color group, the numerical range of saturation values were as shown in Table 2.

3.1.3. Extraction of color information of ear-corn

The color information of the segmented object (ear-corn) were computed from the hue and saturation buffer and was expressed as the hue and saturation color group as discussed above. The flow chart for the entire process for color grouping for the ear-corn images is shown in Figure 3.

The color grouping process based on the color information of kernels did not take into account the color information of the exposed cob. So, provisions were made to include user interaction in defining the exposed cob region by a user defined window. The software computed the average color information of the defined window region and assigned the computed color information as the color of the exposed cob. If the ear-corn image had an exposed cob, the color information of the kernel were determined by subtracting the average cob color information from the computed color information of the segmented object (ear-corn). The color information of the kernels was then expressed in terms of the hue and saturation distribution values and the corresponding hue and saturation based color groups.

3.1.4. Classification of ear-corn into color groups

The hue and saturation based color groups of the ear-corn were then used to determine it's color-group using the color classification program "CLR-RULE" (Figure 3). This color classification program is heuristic based and consists of several rules.

The curator of the Plant Introduction Station, Ames were chosen as the expert for this system. The primary author served as the knowledge engineer and worked with the expert to acquire the required knowledge, derive procedural steps, and construct heuristic rules. Selected ear-corns of seven different color groups were digitized. The hue and saturation distribution values of ear-corns for each color group were determined. From these hue and saturation distribution values, and acquired heuristic, several IF-THEN rules with logical **AND** and **OR** (Table 3) were constructed for the color classification system. One such rule is as follows:

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Rule 07: IF [(CLR2 >= 55) AND (CLR2 < 80)] AND
            [(M_SAT2 > H_SAT2) OR (H_SAT1 > M_SAT1)]

                THEN THE COLOR GROUP IS RED
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The attributes used in this color classification program and their descriptions are shown in Table 3. The decision tree for the classification system is shown in Figure 4. This color classification system follows a TOP-DOWN-APPROACH and utilizes a forward chaining strategy to reach *inference*. The *inference* or *conclusion* of the system can choose one of the possible seven color groups (Figure 4).

This heuristic based rule supervised classification program was tested on eighty randomly selected ear-corns. These ear-corns were of different color groups. The original color group of these ear-corns were predetermined by the expert. The performance of the algorithm was evaluated by comparing the color group assigned by the color grouping system with the original color.

4. RESULTS AND DISCUSSION

Comparisons between the original color groups and the color group assigned by the computer imaging system are shown in Table 5. The overall accuracy of the color classification program was 99%, i.e. the algorithm could classify 79 ears of corn correctly into their respective color groups.

An accuracy of 100% was obtained for classification of yellow era-corns i.e. the classification program correctly classified all 44 yellow ear-corns included in the study.

This color classification program correctly classified all the 4 red ear-corns correctly. The classification accuracy for orange ear-corns was also 100% i.e. all 13 orange ear-corns were correctly classified. All the 4 light orange ears of corn were also correctly classified.

Figure 5 shows a typical example of an ear-corn where the genetical information influences the color group of the ear of corn. Although the color appears yellow, the plant breeders classify it as white from the germplasm characterization point of view. The program correctly classified all 13 white ears of corn.

There were two light brown ear-corn included in the study. The program correctly classified only one of two and the other one was misclassified as red.

From the discussion with the curators of the Plant Introduction Station. Ames, Iowa, it was found that generally, the number of yellow, orange and white ear-corns in the corn germplasm collection are higher than those of other color groups. The high accuracies of this color classification program for yellow, orange and white ear-corns shows promise of adoption of the color computer vision technology for then germplasm characterization process. However, this program needs to be tested on larger sample size and more number of ear-corns from other color groups such as light brown, red and light orange.

This color classification algorithm took an average of 1.1 seconds for each color classification with a range of 0.9 to 1.4 seconds. This time included the background color segmentation, finding the hue and saturation distribution values, and the color group.

5. CONCLUSIONS

The following conclusions were derived from this study

- Ten different color groups were derived based on their hue values. The numeric ranges of the hue values for each color group were defined.

- Each color group was subdivided into low, medium and high brightness groups based on the saturation values. The numeric ranges of the saturation values for each subgroup were defined.

- A heuristic based rule supervised program was developed for color classification of ear-corn images. The program provided an accuracy of 99% i.e. it correctly classified 79 images (out of 80) into their respective color groups.

6. REFERENCES

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Table 1. Visually perceived color groups based on their hue values and their numeric ranges

Color group	Range of hue values	
	low range	high range
Red	0	5
	247	255
Orange	6	22
Yellow	23	52
Green-yellow	53	64
Green	65	93
Blue-green	94	157
Blue	158	175
Violet	176	191
Purple	192	236
Red Purple	237	247

Table 2. Color groups based on brightness/lightness levels for each color and their numeric ranges based on saturation levels

	Ranges of color groups based on satuartion levels		
Color	**Low bright**	**Med bright**	**High bright**
Red	0 - 40	41 - 140	141 - 255
Orange	0 - 80	81 - 168	169 - 255
Yellow	0 - 88	89 - 168	169 - 255
Green Yellow	0 - 80	81 - 136	137 - 255
Green	0 - 80	81 - 168	169 - 255
Blue green	0 - 73	74 - 152	153 - 255
Blue	0 - 80	81 - 144	145 - 255
Violet	0 - 80	81 - 144	145 - 255
Purple	0 - 80	81 - 144	145 - 255
Red Purple	0 - 80	81 - 144	145 - 255

Table 3. Description of the *attributes* used in development of heuristic rules for classification of color group of ear corn image

Attributes	***Description***
CLR1	RED COLOR
CLR2	ORANGE COLOR
CLR3	YELLOW COLOR
H_SAT1	HIGH BRIGHTNESS OF RED COLOR
M_SAT1	MEDIUM BRIGHTNESS OF RED COLOR
H_SAT2	HIGH BRIGHTNESS OF ORANGE COLOR
M_SAT2	MEDIUM BRIGHTNESS OF ORANGE COLOR
H_SAT3	HIGH BRIGHTNESS OF YELLOW COLOR
M_SAT3	MEDIUM BRIGHTNESS OF YELLOW COLOR

Table 4. The results of color grouping program on eighty randomly selected ear-corns.

Original color group	no. of samples	no. of samples correctly classified	% of accuracy
Yellow	44	44	100%
Orange	13	13	100%
Red	4	4	100%
Light Orange	4	4	100%
White	13	13	100%
Light Brown	2	1	50%
	80	79	99%

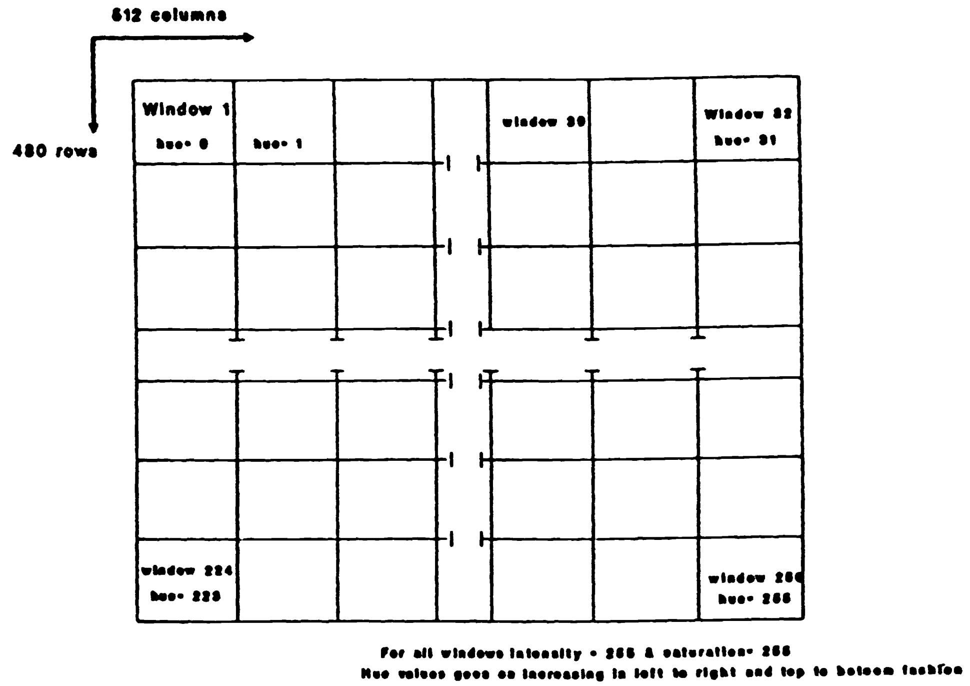

Figure 1: Schematic of windows for finding the numeric ranges of different hue based color groups

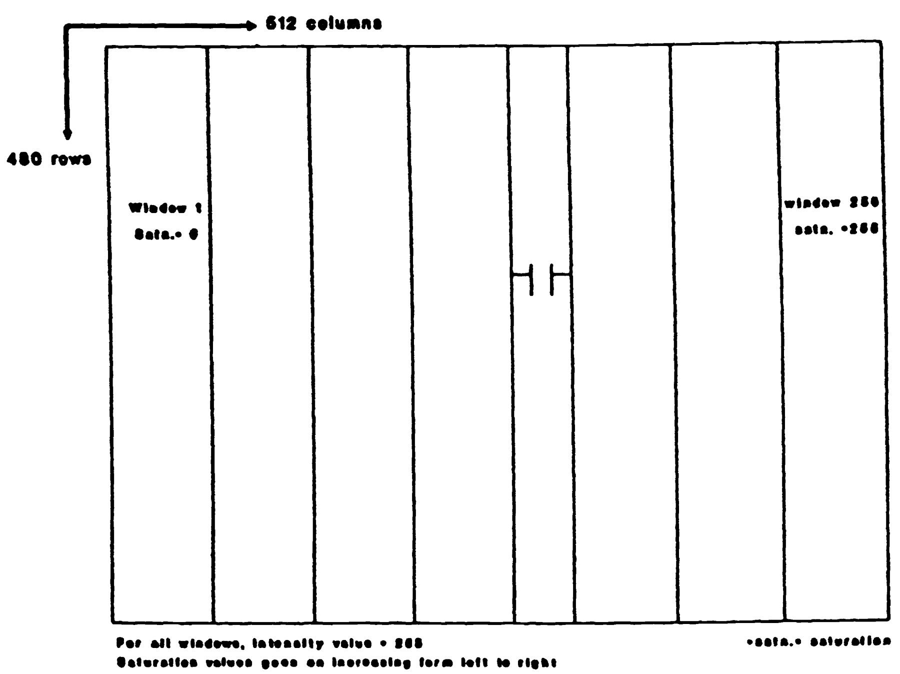

Figure 2: Schematic of windows for finding the numeric ranges of different saturation based color groups

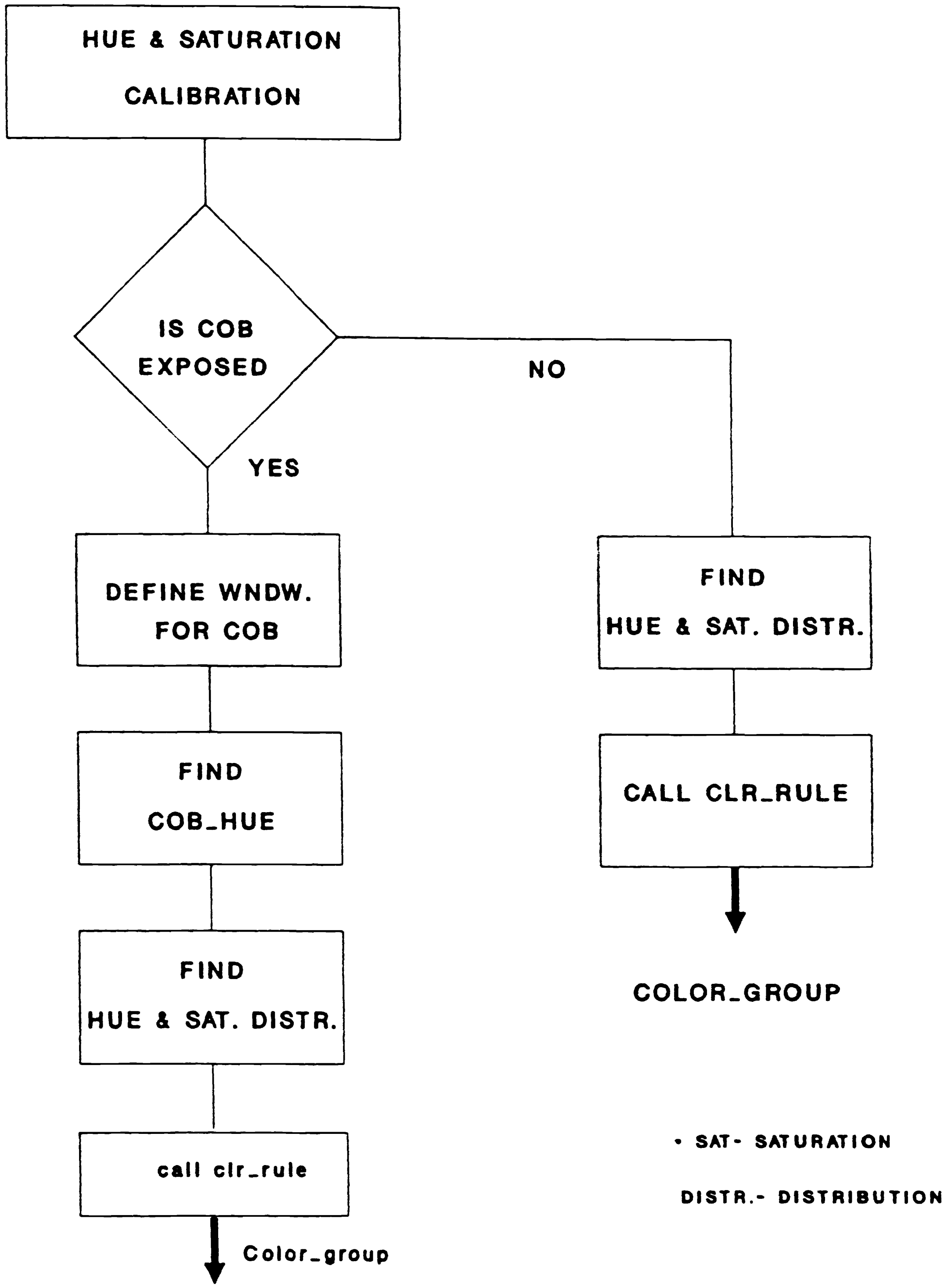

Figure 3: The flow chart for clolor classification process of ear-corn images

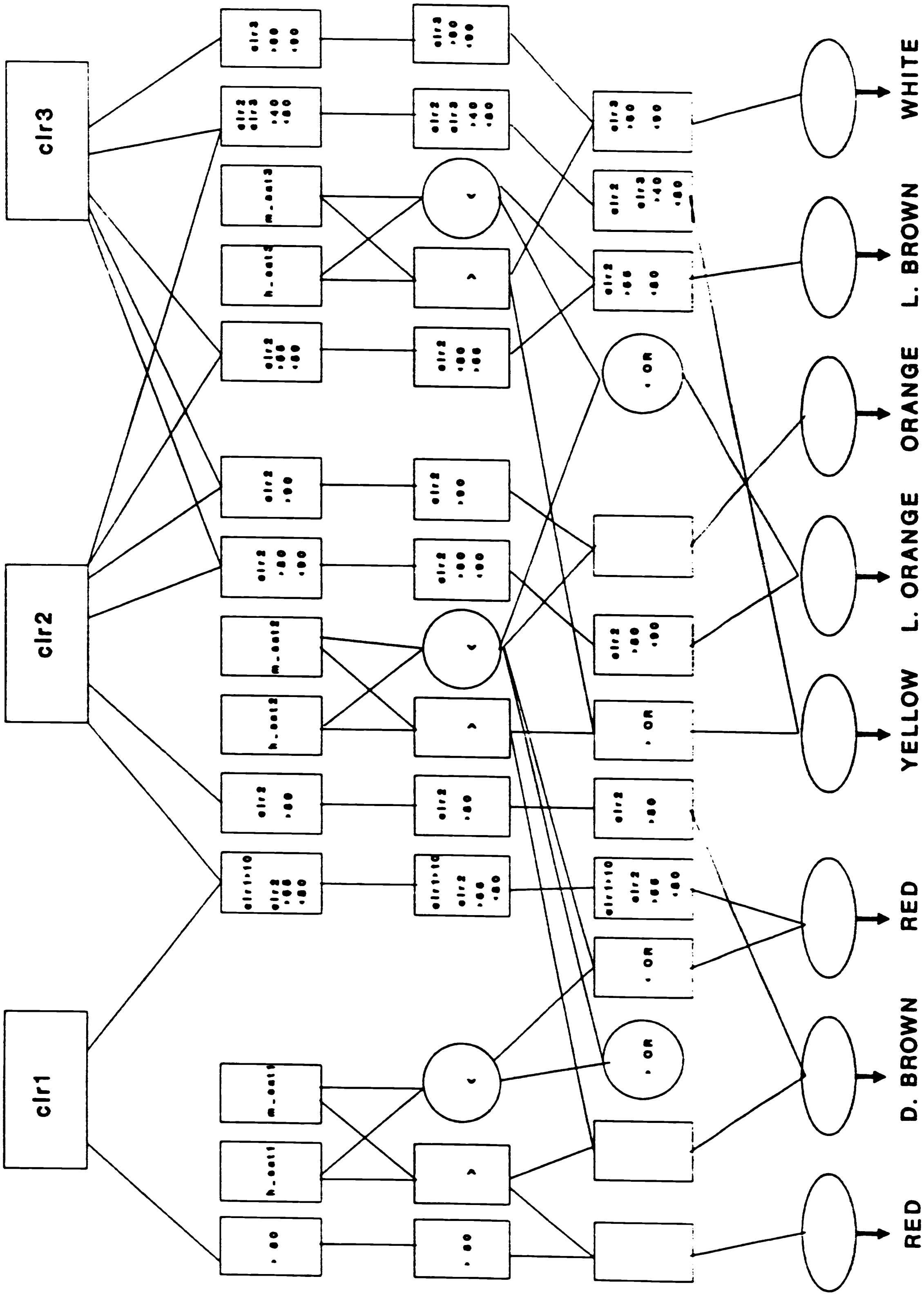

Figure 4. The decision tree for heuristic based color classification system

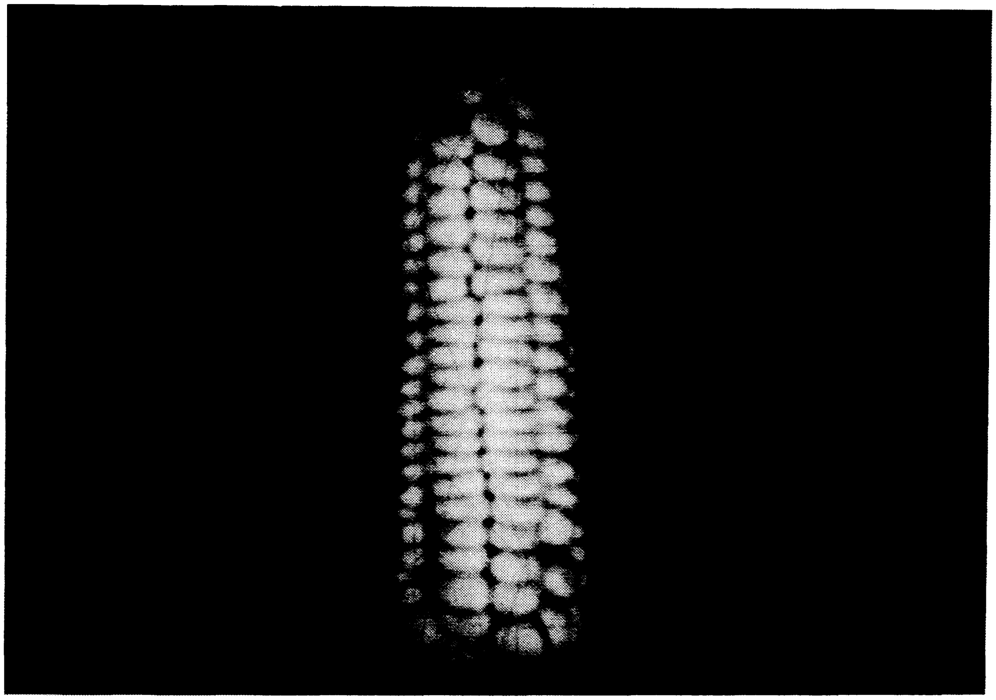

Figure 5: The digitized image of a typical ear-corn correctly classified as white by the computer vision system.