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Detection of a Spot of Pre-defined Color Using a Video Color System in the Context of Robotics

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Abstract: In robotics, vision provides the control system with vast amounts of data concerning the manipulator itself and its environment. Many different image identification techniques have been proposed since the introduction of vision systems to robotics, but as the size of data is large, most of these techniques require so long computation times, not applicable at shop floor. This paper suggests the use of specific colors which are unique to the object of interest enabling their detection and hence distinction from the rest of the environment easily, irregardless of the details and intricacy they may bear. Such brightly colored spots can be put on an object in precise locations during manufacturing. The problem then comes up as to search the color definitions of the pixels forming the image and select the ones which fit to the pre-defined color. In this paper, to define the ability of distinguishing colors, *Colorimetric System*, *Nevatia Transformations* and *NTSC Color Systems* are tested and results are presented.

Key Words: Computer Vision, Colorimetric System, Nevatia Transformations, NTSC Color System.

Robotik Uygulamalar İçin Video Sistemlerle Belirli Renkte Bir Beneğin Çevresinden Ayırt Edilmesi

Özet: Endüstriyel robotlarda video-görüntü sistemleri manipülatörün kendisi ve çevresi hakkında çok miktarda bilgi sağlarlar. Görüntü sistemlerinin robotlara uyarlanmaya başlamasından bu yana birçok değişik görüntü tanımlama teknikleri önerilmiştir. Fakat işlenecek bilgi miktarının çok olması ve hesaplama zamanın uzunluğu bu tekniklerin çoğunu atölye ortamlarında kullanılamaz hale getirmektedir. Bu makale robot tarafından tutulacak cismin üzerine ortamda olmayan değişik bir renk boya kullanılarak tanımlayıcı benekler konmasını önermektedir. Bu şekilde belirgin renkte benekler cisim üzerine imalat sırasında hassas koordinasyon ile konulabilir. Bu aşamada problem görüntüyü oluşturan piksellerin renk tanımlarının belirlenmesi ve aranan renge uyanların ayrılması olarak ortaya çıkmaktadır. Bu makalede renk tanımı ve ayrımı için Colorimetik Sistem, Nevatia Transformasyonları ve NTSC Renk Sistemleri denenmiş ve test sonuçları sunulmuştur.

Anahtar Kelimeler : Görüntü İşleme, Colorimetic Sistem, Nevatia Transformasyonu, NTSC Renk Sistemi.

Introduction

In robotizing a task, the cost of extra machinery required to place the object to be manipulated to the correct position and angular orientation is often neglected. Jigs, fixtures, conveyors, indexers and devices alike, automatic to some extent, are externally provided and are nearly the same price as the robot. More intelligent robots are equipped with more intricate sensory devices and with proportionally sophisticated software to replace these extra machinery. Vision provides the control system vast amounts of data concerning the manipulator itself and its environment. A machine vision system captures an image with a camera and analyzes the image to produce a description of the objects viewed. The input to a machine vision system is an image while its output is a set of numbers describing the color and brightness levels of pixels, which can be quickly extracted from the image and whose features contain enough information to permit decision. An object usually does not have a unique description and hence it is impossible to describe it completely. Generally a complete description of all the objects in the image is seldom necessary. Instead, features special to the object under consideration are determined and are sought for. Extent of the special features can vary according to the task at which image identification is used. Symbolic representation of an object must be known and this symbolic representation is to be interpreted and compared with that of the image by a computer.

Fundamental knowledge required from a machine vision system is the location and angular orientation of the object under consideration, disregarding all the other details embedded in the image. To extract this knowledge, 6 independent quantities must be measured as the total degrees of freedom in space is 6. In practice, this is obtained from the coordinates of 3 non-coinciding points on the object, totally 9 numbers, 3 of which being redundant. Redundant data are eliminated by 3 constraint equations describing the rigidity of the object as the distances between any pair of points are constant . 3 spots of distinct color, size and spacing can be put on an object at precise locations while it is being manufactured. x,y,z coordinates of these points are extracted from vision. This method can define not only the location and orientation of an object, but its type as well, from the color, size and spacing of the spots.

The first problem hence is to detect patches of certain color definition, somehow different from all the other parts of the image. The color is an important parameter to aid the identification. Healey, G. describes color discrimination by a computer, defining colors by their wavelengths in his paper published in 1989. Wandell, B. has put the use of color in image identification and reported this in his 1987 paper. Brockelbank, D.C and Yang, Y.H have applied stereovision techniques on color images to yield surface structures of solid objects and reported this in their paper published in 1989. To define the color of a pixel, there are different standards. In this work, machine components are identified by the color and spacing of 3 spots put onto the component at precision locations presumably when it is in precision coordination like in a chuck during manufacture. When the coordinates of any 3 non-coinciding points on a rigid body are known, the location and angular orientation of the object are derivable. Usefulness of this approach is demonstrated by experiments.

Color Systems

A particular color is described in terms of attributes of brightness, hue and saturation. Intensity or brightness is the attribute that is perceived in achromatic images. Hue represents dominant color as perceived by an observer. For example, red is of different hue from green. Saturation refers to relative purity or the amount of white light mixed with a hue. The pure spectrum colors are fully saturated.

Human perception of achromatic pictures is quite satisfactory, but the color pictures do seem to be perceptually richer. Different objects may be expected to have different colors, and hence color discontinuities are keys in the identification of color images. It is commonly accepted that a complete description of a point in a color image requires the specification of three mutually independent parameters. These are called the primary colors which are red (R), green (G), and blue (B).

In this work, to define colors, Colorimetric System, Nevatia Transformation, and NTSC Color Systems are discussed. Colorimetric system is the basis of defining different colors. It is explained in detail by Gonzales, R.C and Wintz, P. in their book published in 1987. Nevatia, R. brings a new definition of color by a set of transformation formulas, given in his 1977 paper. NTSC color system is explained in detail by Lim, J.S, in his book published in 1990 .

Colorimetric System:

This system is based on the fact that any color can be matched by a combination of three spectral wavelengths of light in red, green and blue regions. The amounts of red, green, and blue needed to form any given color are called the tristimulus values and are denoted respectively by X, Y, and Z. In a computer video system color components of a pixel are stored in a digital manner. For 24 bit storage, 2^{24} or 65536 different and detectable levels of color components are possible. Computers can compare the components of each pixel of the image on its screen with colors of known combination and denote the levels of the color components. Color components X, Y, and Z are hence integer numbers between 0-65535, defined software wise. A color is then specified by its thrichromatic coefficients as:

$$x = X / (X+Y+Z)$$
$$y = Y / (X+Y+Z) \qquad (1)$$
$$z = Z / (X+Y+Z)$$

It is evident from these equations that:

$$x+y+z=1 \qquad (2)$$

Hue and saturation taken together are called chromaticity, and therefore a color is defined by its brightness and chromaticity. The Commission Internationale de l'Eclairage (CIE) chromaticity diagram is shown in Figure 1 with the description of the various color regions. x, y, and z form a right handed Cartesian frame. The colors form a humping surface, at the crest of which perfect white at coordinates (1/3,1/3,1/3) is found. Red, green and blue are equally spaced around white and change from one to another and to

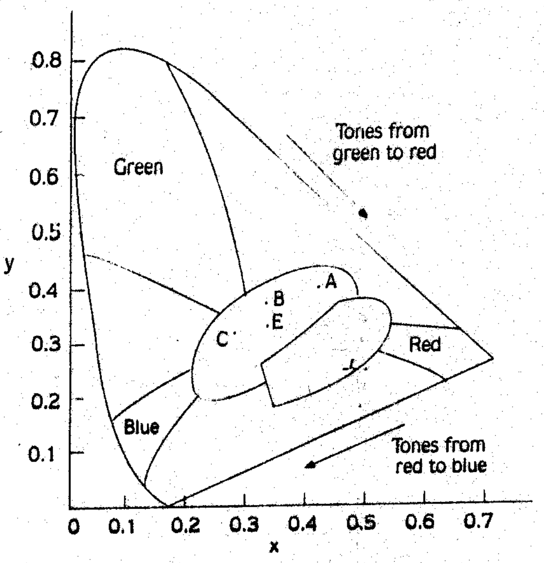

Figure 1. The CIE 1931 Chromacity Diagram with Descriptions of the Various Color Regions. A, B, and C Represents the Positions of Standard Sources Roughly Equivalent Gas-filled Incandescent Lamps, Noon Sunlight, and Average Daylight, Respectively. E Represents the Equal Energy Point Corresponding to Perfect White.

white at the crest gradually. For a color spot to be perceived as *red* for example, its thricromatic coefficients must be as:

$$x > 1/3 \quad y < 1/3 \quad z < 1/3 \tag{3}$$

Nevatia Transformation:

Nevatia sets a new coordinate system to the chromaticity diagram shown in Figure 1 with the following transformation which he has reported in his 1977 paper:

$$Y = c_1R+c_2G+c_3B \quad T_1 = R/(R+G+B) \quad T_2 = G/(R+G+B) \tag{4}$$

Y is the brightness of the pixel. R, G, and B are the red, green, and blue levels of a pixel respectively, each being an integer number between 0-65535 in a 24 bit system. This is synonymous to the X, Y, and Z in colorimetric system. c_1, c_2, and c_3 are arbitrary constant numbers such that :

$$c_1+c_2+c_3 = 1 \tag{5}$$

T_1 and T_2 together give the chromatic information about a pixel color. Note that T_1 and T_2 are independent of the brightness Y. Transformation of chromatic information into T_1 - T_2 space is viewed conveniently by the color triangle shown in Figure 2.

Pure blue is at the origin where T_1 and T_2 are both zero. At $T_1 = 1$, $T_2 = 0$ is the pure red and at $T_1 = 0$, $T_2 = 1$ is the pure green. Perfect white is at $T_1 = T_2 = 1/3$. T_1 and T_2 together describe a location on the chromaticity surface uniquely. Another way of representing a point is to shift the origin to perfect white at $T_1 = T_2 = 1/3$ and define polar coordinates r and ϕ as shown in Figure 2. A color spot perceived as *red* for example has coordinates at:

$$T_1>1/3 \text{ and } T_2 < 1/3 \tag{6}$$

NTSC Color System:

The three tristimulus values red (R), green (G), and blue (B) are transformed into another set of tri-stimulus values denoted by Y, I, and Q, which are re-lated to R, G, and B by:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.272 & -0.322 \\ 0.211 & -0.523 & -0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{7}$$

and

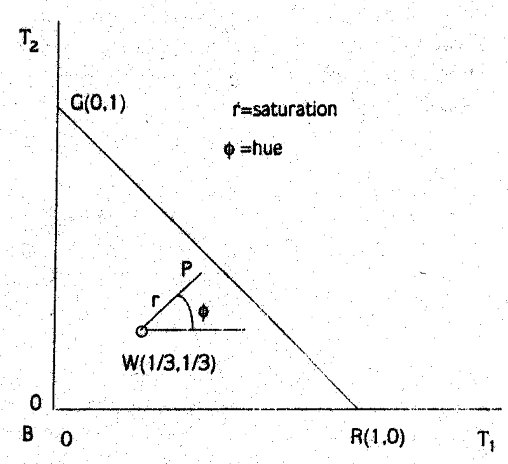

Figure 2. Color Triangle Representation of Chromacity Values. R,G, and B Represents Pure Tones of Red, Green and Blue Respectively.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.621 \\ 1.000 & -0.273 & -0.647 \\ 1.000 & -1.104 & 1.701 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad (8)$$

The Y component is called the *brightness component* since it roughly reflects the luminance sensation of the color. It is primarily responsible for the perception of the brightness of a color image and can be used to form a black and white image. The I and Q components are called the *chrominance components*, and they are primarily responsible for the perception of the hue and saturation of a pixel. In the NTSC color system, threshold values T' and T" for the hue and saturation respectively can be arbitrarily defined for a certain color and while searching for it, the conditions:

$$I > T' \text{ and } Q > T'' \quad (9)$$

are sought for.

Computer Vision System Hardware

The hardware used in this work consists of a PULNIX TMC-74 (NTSC) color video camera, a Raster Ops Video Color Board 364, and an Apple Machintosh fx II computer. Pulnix TMC color camera has a high resolution 2/3 inch imager having 768x493 light sensitive cells each of 11x13 microns size, and an automatic iris. Raster Ops Video Color Board 364 has a palette size of 16.7 millions, each pixel definable by 1,2,3,8, or 24 bits, and a resolution of 640x480 pixels. It works in NTSC mode with a scanning speed of 30 Hertz. Central processing unit of the computer is the MC 68030, with a 32 bit architecture, running at a clock frequency of 25 MHz. An MC 68882 Floating Point Unit Co-processor with 40 MHz clock frequency has been installed into it to speed up arithmetic/logic operations. The Processor has a memory of 8 MB RAM,and 512 KB ROM. One 1.4 MB high density floppy disc drive, and a 200 MB internal Apple SCSI hard disc drive are also mounted on the system.

Searching Method

The following procedure illustrates how a color patch is found by using a certain color system. The indoor scene or frame in camera view is first grabbed. The frame is then searched for a specific color spot. The search begins at the origin of the scene, which is the upper-left hand corner of the monitor at pixel location (0,0). In the *raster scan fashion* search is done row by row, always starting at the first column of each row and ending at the last. The screen has 640X480 pixels and the specific color being searched can be at anyone of these pixels, hence pixel by pixel search may take quite a long time. In this work, to reduce the amount of computation, firstly a window of 300X300 pixels are activated for the grabbed image. Computer analyses each pixel and returns its R,G and B values. Real time to analyze all of 300X300 pixels with the hardware at hand is about 30 seconds. This is quite a substantial amount of time to identify an object for a robot system at shop floor. Secondly, to reduce the processing time, *method of bisection* can be used instead of *raster scan search*.

In this method image window is searched column by column starting from the top of the window to bottom. The first pass of search starts at the middle or 150 th column. If the required color is not detected in this search, second search is done on the halfway column of the strip on either side of the middle column, that are columns 75 and 225. The procedure continues in this manner, taking the middle column of the remaining strip until finding the required color at anyone of the pixels. Then a suitable size window is set which presumably contains the whole of the patch and all the pixels in this secondary window are searched for. The program segment for the search is written in C programming language.

Experimental Results

The first problem in the identification and determination of coordinates and angular orientation of an object by 3 *point method* is the detection of a spot of specific color. The machine vision system used hence must be able to distinguish the color of this spot from the rest of the scene and also keep the shape and size of the spot. Once the spots are determined, their centroids will be found and each spot of finite area will be replaced by a point located at its centroid. The vision system to go with a shop floor robot must be cheap, not so much sophisticated and still able to fulfill the above mentioned requirements at adverse conditions of vision. Once the image is captured, the points of interest can be perceived easily by a human, but in an automatic and continuous operation, search is to be done by the computer and it must be reliable. Illumination problems generate great difficulties. Variation in the type and location of the lights may alter all color definitions. Similarly, contribution of daylight to illumination always varies throughout the time of the day. At a certain position, incident light may reflect on a surface altering all the color definitions. There can be unintended shadows on the object, or definitive color patches may become dirty in shop floor environ-

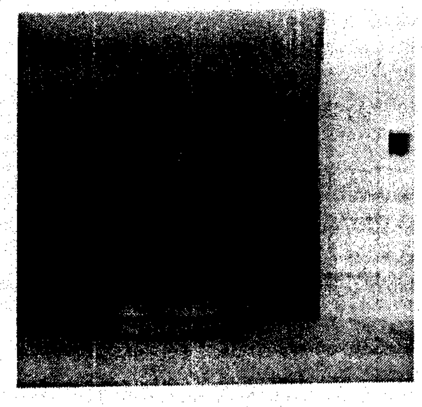

Figure 3.a

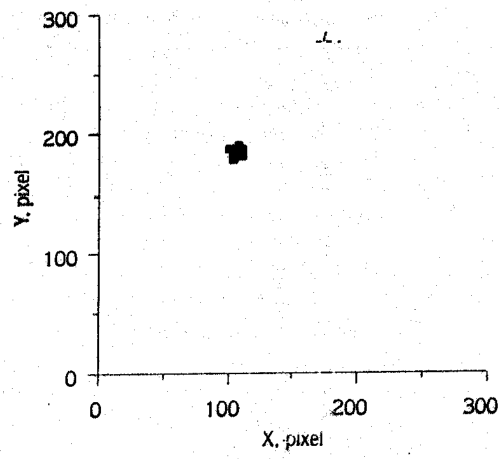

Figure 3.b

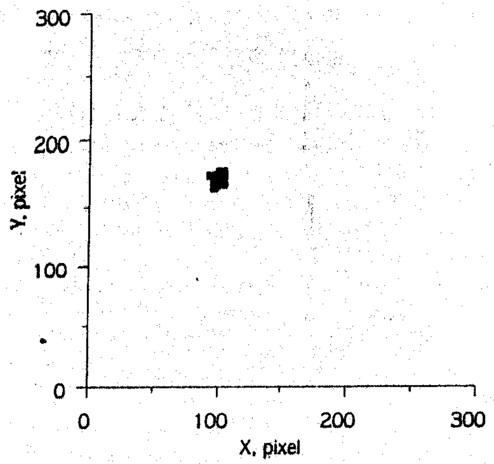

Figure 3.c

Figure 3. A 13X15 mm Rectangular Red Patch on the Cylindrical Surface of a Non-painted Steel Machine Component (a). Binary Images (b) and (c) Show the Red Color of the Original Image Filtered by Nevatia and NTSC Color Systems Respectively. Illumination is by Natural Diffused Day Light.

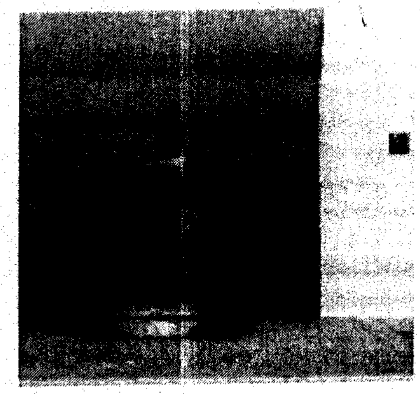

Figure 4.a

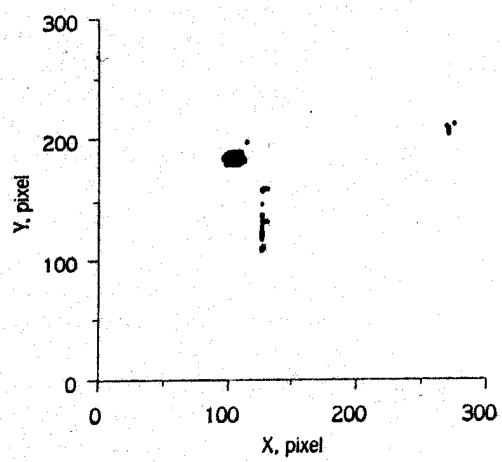

Figure 4.b

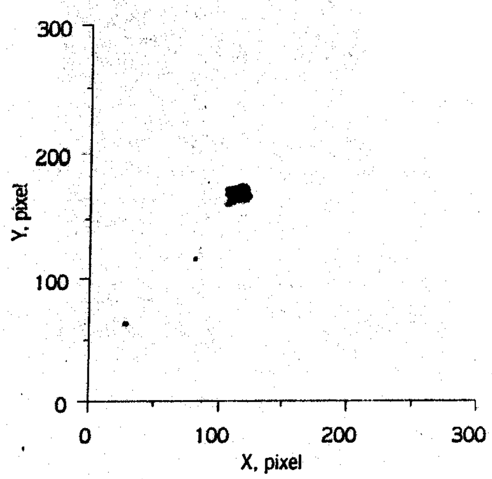

Figure 4.c

ment. If a color patch is adequately illuminated and illumination conditions are fixed, then its detection by the computer becomes easy, but under varying condi-

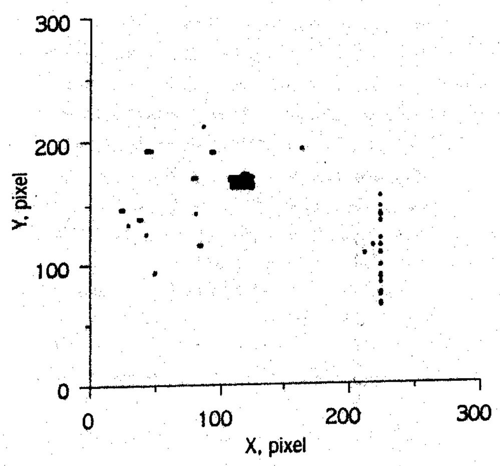

Figure 4.d

Figure 4. Image of the Same Object in Figure 3 (a), Illuminated by a Tungsten Lamp Located Behind the Camera (a). (b), (c), and (d) Show the Red Color of this Image Extracted by Colorimetric, Nevatia and NTSC Color Systems Respectively. Strong illumination Causes False Points in Red Color.

tions of illumination, precautions must be taken and hence the advantages and disadvantages of various color systems become important.

The first experiment is about the detection of a single, relatively large spot in red. The spot is a 13X15 mm rectangular piece of plastic sheet stuck on an unpainted steel machine component as shown in Figure 3-a. The spot is put on a cylindrical surface such that reflections of light are present. There is no

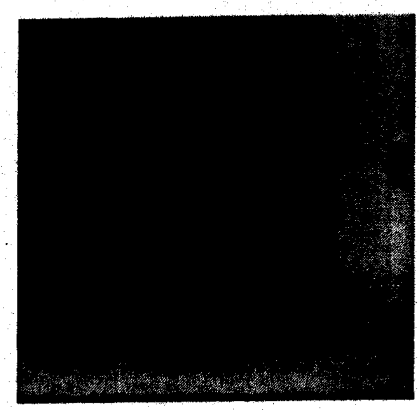

Figure 5.a

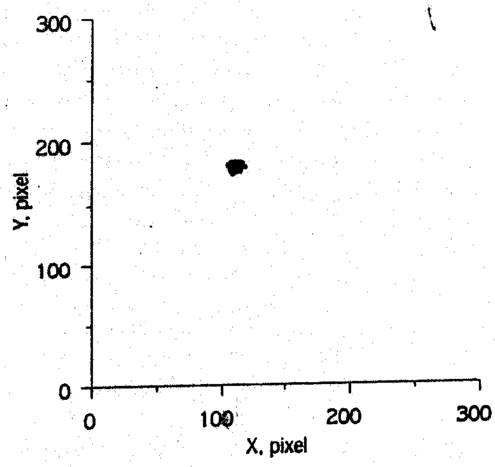

Figure 5.b

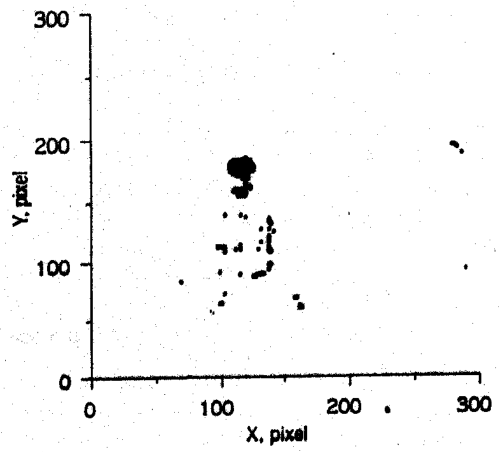

Figure 5.c

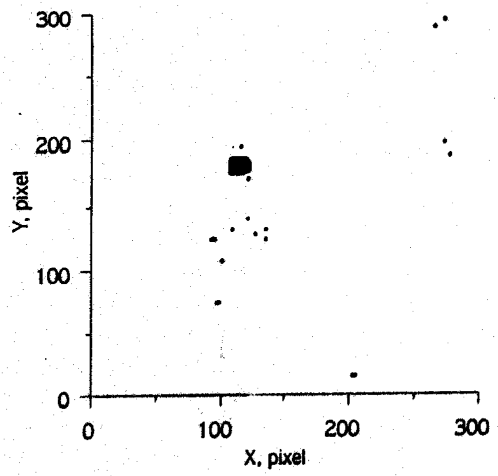

Figure 5.d

Figure 5. Image of the Same Object in Figure 4 (a), Illuminated by a Fluorescent Light. There is no Daylight Component in Illumination. (b), (c), and (d) Show the Red Color of this Image Extracted by Colorimetric, Nevatia and NTSC Color Systems, Respectively.

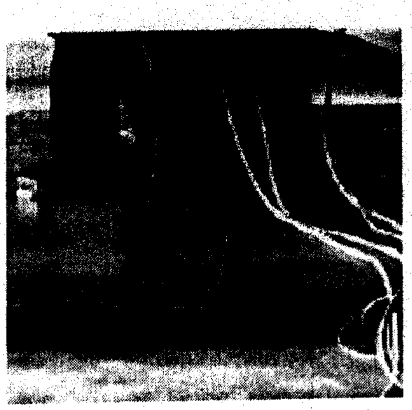

Figure 6.a

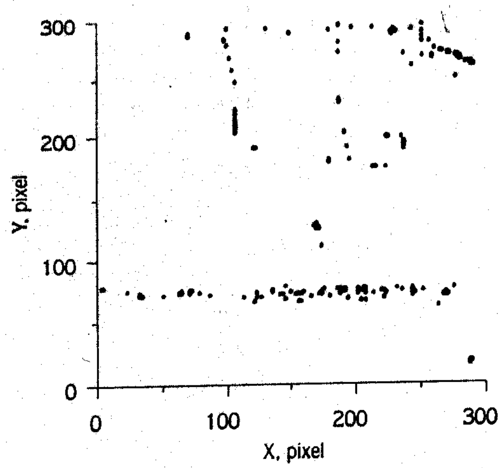

Figure 6.b

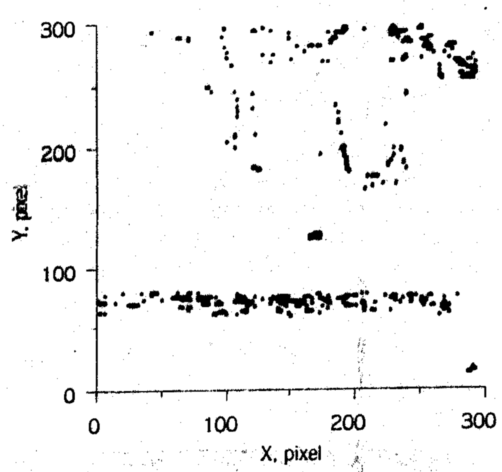

Figure 6.c

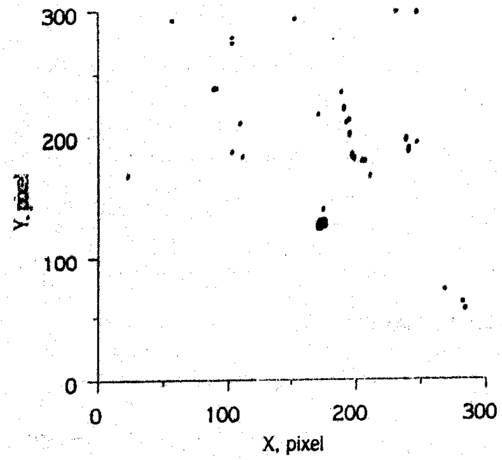

Figure 6.d

Figure 6. Object of Figure 3 is Displaced from the Camera 5.3 Metre (a). Red Filtered Binary Images are Shown in (b), (c), and (d). Color Definition is by Colorimetric, Nevatia and NTSC Systems, Respectively. NTSC System Produces Dominantly Better Results with Less False Points.

incident light, other than natural diffused daylight. The original color image is captured in a 300X300 pixel window with a lens of 50 mm focal length, from a distance of 135 cm. Figure 3-a shows the image in gray tones. The window is scanned pixel by pixel in *raster scan fashion*. Color definition of each pixel is found by the computer in form of an integer number up to 65535, for red, green, and blue. Then, this data is converted into Colorimetric, Nevatia, and NTSC definitions. In Colorimetric system different tones of red are described by equation (3). When the colorimetric base data are examined, no pixel is found satisfying this condition. In Nevatia system, tones of red are described by equation (6). When the Nevatia base data are examined, some pixels are found satisfying this condition. A new sketch for the window is prepared showing only these pixels in black which are completely distinguished from the rest as seen in Figure 3-b, known as the ***binary form of the red filtered image***. Similarly the NTSC base data is examined in accordance to equation (9) with threshold limits T'=T"=2000. The binary image showing only the pixels satisfying this criterion in black is shown in Figure 3-c. Colorimetric system has failed to detect a relatively large size patch while Nevatia and NTSC systems have defined almost the same spot, at the right position and with right dimensions. Size of the red patch shown in the window of Figure 3-a is exactly the same as that of the binary images of Figures 3-b and 3-c. So, loss of geometric details are negligible.

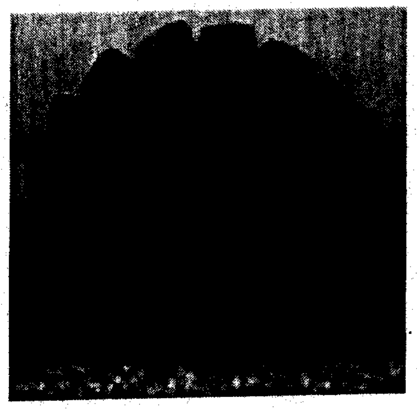

Figure 7.a

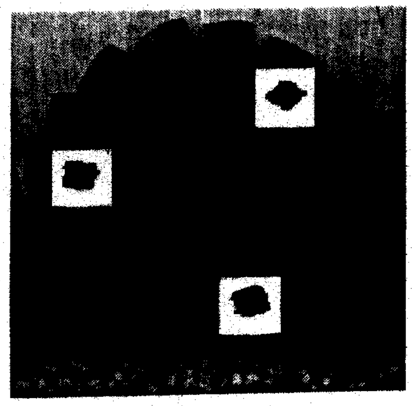

Figure 7.b

Figure 7. View of a Gear in Gray Tones under Diffused Daylight Illumination (a). Secondary 45X45 Pixel Windows are used Which Presumably Cover the Spots Fully. Characteristic Color Pixels are Found by Using the Bisection Method (b). Color System used is NTSC with Threshold Limits of T'=T"=2000. Processing Time is 10 Times Less than the Raster Scan Fashion.

Second experiment is the repetition of the first with incident light coming from a tungsten lamp located behind the camera. Object is better illuminated as seen in Figure 4-a, but there are strong reflections and white light is effective on the environment with all its color components. Red, Green, and Blue color data are converted into Colorimetric, Nevatia, and NTSC bases and binary images showing only the pixels containing definition of red color are given in Figure 4-b, 4-c and 4-d respectively. Better illumination has made the red spot visible in all color systems. Besides the required red spot, some other pixels are also found to satisfy the definition of red. These are mainly due to the reflections and chromatic aberration occurring in the lens. Large patches in Figures 4-b, 4-c and 4-d represent the red spot. Others are false points. False points are smaller in size, but there can be larger patches of them. So, filtering the false points becomes necessary. The sizes of the patch in red filtered images comes up larger than normal due to chromatic aberration at the patch boundaries.

Another cheap means of illuminating a certain object is by fluorescent lamp. To see how definitive is a certain color in fluorescent illumination, the same object with its red spot is illuminated by fluorescent light at night time when daylight component in illumination is null and observed by the camera. What camera *sees* is shown in Figure 5-a. Visual details are greatly lost in human perception. The red-filtered form of the same image in Colorimetric, Nevatia, and NTSC color systems are shown in Figures 5-b, 5-c, and 5-d respectively. Nevatia and NTSC system generate false points and the size of the red patch comes up larger than original. Colorimetric system is less sensitive and produces no false points and has a smaller patch size.

As seen in experimental results, Nevatia and NTSC systems have produced the best results in diffused daylight, but at workshop environment, there can be a combination of daylight and artificial light. Work environment can be specifically illuminated for better perception. Also false points can be filtered software wise. In general, NTSC produces the best results with least loss of the spot geometry and least number of false points. The size of the spot to see is naturally important. Larger the size, larger its image and hence distinction of them from false points is easier.

Viewing an object from a longer distance causes loss of details. To display the effect of distance, object viewed in Figure 3 is placed to a distance 5.3 meters from the camera. Figure 6-a shows what the camera sees in gray tones. Binary images, red filtered according to Colorimetric, Nevatia Transformations and NTSC Color System are shown in Figures 6-b, 6-c and 6-d respectively. As the relative size of the spot in comparison to the window has become smaller, problems of detection have arised. A criterion to distinguish a functional patch from the false points can be the use of larger patches in size. As false points are smaller, a distinction can be made due to size. All binary images of Figure 6 contain false points. Colorimetric system can not distinguish the red spot at all. Nevatia system gives a good view of the spot but with too many false points, producing a great identification problem. NTSC system gives a good view of the patch and less number of false points hence NTSC system comes up better, but still filtering of false points is necessary.

To filter the false points, 3X3 *pixel masking* is used. In this method of masking, when a red pixel is detected, the color of the 8 surrounding pixels are checked. If 6 of these are also red, than the particular pixel is regarded as part of the functional spot. This method though effective, takes a duration like 33 seconds for a 300X300 pixel window. At this stage method of bisection can be introduced to reduce the computation time.

Figure 7-a shows a gray tone image of a gear containing 3 separate red spots on. The image is scanned columnwise by *bisection method*, searching for a red pixel which passes the 3X3 pixel masking. Once such a point is detected, a sub-window of 45X45 pixels is opened about it which certainly contains one of the patches in full. In the end a total of 3 such windows are formed, one for each patch. Then the inside of these smaller windows are searched only pixel by pixel while 3X3 pixel masking is still active. The corresponding windows and the binary forms of the spots are shown in Figure 7-b. Here, there is the restriction of one window to contain only one patch. This requires the knowledge of dimensions of the patches and the spacing between them priori. Problem is still solvable by searching for *closed polygons*, or by *region growing*. Total time required for finding the 3 spots of Figure 7 in full and free from false points is about 3 seconds, hence, the computation time has been reduced approximately to one tenth.

Conclusions

Among the three methods of defining a color examined in this work, NTSC system brings a more precise definition and hence distinction of different colors is easier with it. Illumination plays an important role and hence even at shop floor, a specific and intense illumination is more preferable. To filter out false points techniques like pixel masking should be used. The size of the spots must be as large as possible and also the relative size of those spots with respect to the window must be as large as possible. A variable focal length camera which can zoom in command of the control computer becomes very useful in this respect. Method of bisection reduces the probable time of detecting a color by pixel search of raster-scanning. Opening a suitable size window whenever such a pixel is detected and searching only this window further reduces the computation time. Experiments in this work have shown that by these techniques, 3 spots on an object can be detected in a duration of about 3 seconds, which is certainly allowable at industrial applications.

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