Fundamentals and methodology of chromatic monitoring: Review

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Abstract— This paper deals with a short review on Fundamentals and methodology of chromatic monitoring. The chromatic approach shows the ability to quantifying information content of signal by chromatic parameters hue (H), saturation (S) , lightness (L) and x, y, z which can be related to characteristics of signal.**Index Terms—**partial discharge, ultra-high frequency method, gas insulation substation, transformer and power cable

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1 INTRODUCTION

CHROMATIC techniques have been used in many applications where accuracy and cost effectiveness are important. Chromatic modulation is employment of polychromatic light for sensing changes in a physical system [1]. It is based on the detection of changes in spectral profile of optical signal. The detection of chromatic changes is measured by monitoring the sum of contributions of relative changes at all wavelengths within a spectral power distribution. Chromatic changes can be monitored by three photo detectors with over lapping spectral response [2,3]. It has been successful applied in plasma monitoring, in electric circuit monitoring for circuit breakers and in the monitoring of aircraft fuel where air and water are present. The chromatic modulation technique used in the optical domain was also reported to be applicable in the acoustic domain for in-process monitoring of laser materials processing. The advantages of chromatic monitoring include high optical detection efficiency due to integrative wavelength detection involved, effective broadband, good response to changes throughout the spectrum and insensitiveness to light intensity changes across the entire spectral region, fast, simple, sensitive, and cost effective.

2 CHROMATIC METHODOLOGY

The chromatic methodology was originally conceived as an efficient and robust method of detecting changes in optical

signals. The technology utilises broadband light sources and detects changes in the optical spectrum received at the detectors. The technique is optically efficient because it is integrative in nature and computationally efficient. The output of a chromatic system consists of only 2 or 3 values. Chromatic systems tend to be less prone to external effects such as light level variations, and have been found to be robust enough for use in an industrial setting. A chromatic detection system can be considered as a truncated Gabor transform [4,5]. The chromatic methodology is shown in Figure 1. The output signals from three detectors as shown in Figure 1 (a). The normalization of R, G, B signals is shown in Figure 1 (b). From the frequency spectrum, the R, G and B components are selected with the help of three Gaussian detectors as.

Conversion to HLS parameters or any other chromatic representations is carried out using equations (5) - (12). The resulting conversion is shown in Figure 2 (c). The hue (H) is the dominant wavelength represented by the circle. The lightness (L) is the intensity represented by the amplitude value on the circular plane. The saturation (S) is the bandwidth represented by the radios of the circle.
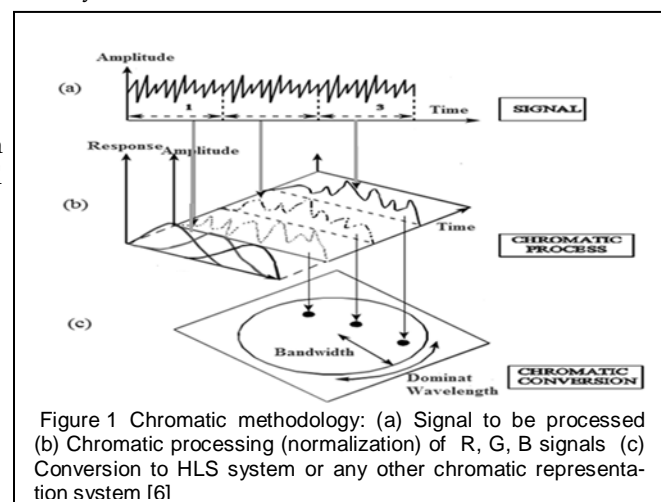
Figure 1 Chromatic methodology: (a) Signal to be processed (b) Chromatic processing (normalization) of R, G, B signals (c) Conversion to HLS system or any other chromatic representation system [6]

3 Chromatic modulation

A chromatic modulation system consists of a source of polychromatic light for sensing changes related to the progress of a physical process and an array of photo detectors with overlapping wavelength-dependent responses R(λ) for chromatic detection. An example of the form of response from three photo detectors is shown in Figure 2. When the detectors are used to monitor an optical signal having a spectral power distribution P(λ) the output voltage V from each detector will be:

$$V = \int_{\lambda}^{\lambda} P(\lambda)R(\lambda)d\lambda \qquad (1)$$

Relative spectral responses of three photo detectors as shown in Figure 2. In general, three detectors provide the optimum arrangement for most applications. Let the responses of the detectors be Rx(λ), Ry (λ), and Rz (λ), respectively, each detector gives an output voltage as follows [7-10]:

$$V_x = \int_{\lambda}^{\lambda} P(\lambda)Rx(\lambda)d\lambda \qquad (2)$$

$$V_y = \int_{\lambda}^{\lambda} P(\lambda)Ry(\lambda)d \qquad (3)$$

$$V_z = \int_{\lambda}^{\lambda} P(\lambda)Rz(\lambda)d\lambda \qquad (4)$$

Figure 2   Relative spectral responses of three photo detectors [11]
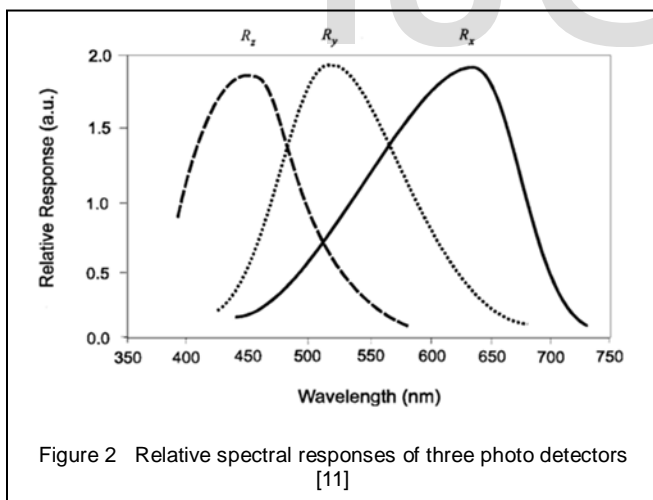
4 Chromatic transformation

Chromatic transformation involves the use of one of several algorithms for producing chromatic maps from the raw R, G, B values. Two useful forms of transformations are those based upon parameters H, L, S (which yields signal feature defining parameters) and parameters x, y, z, (which compares the relative magnitudes of the output signals).

a) Basic HLS transformation

Hue-Lightness-Saturation scheme of colour science is the basis for basic HLS transformation [12]. HLS transformation involves the cross correlations between an unknown signal and the different responses of each of the three R, G, B detectors as shown in Figure 3. In this transformation process, RGB are converted to HLS yielding signal structure information via the chromatic parameters H, L, S. The dominant wavelength is obtained from the signal parameter H, the signal strength or energy level is obtained from the signal parameter L while the spread or the excitation purity is obtained from the signal parameter S. The transformation algorithm is described as follows:

$$max = \text{Maximum} (R, G, B)$$
$$min = \text{Minimum} (R, G, B)$$

$$r = R - min \qquad (5)$$

$$g = G - min \qquad (6)$$

$$b = B - min \qquad (7)$$

$$\text{If } R = min, \; H = 120 \times \left(\frac{g}{g+b}\right) \qquad (8)$$
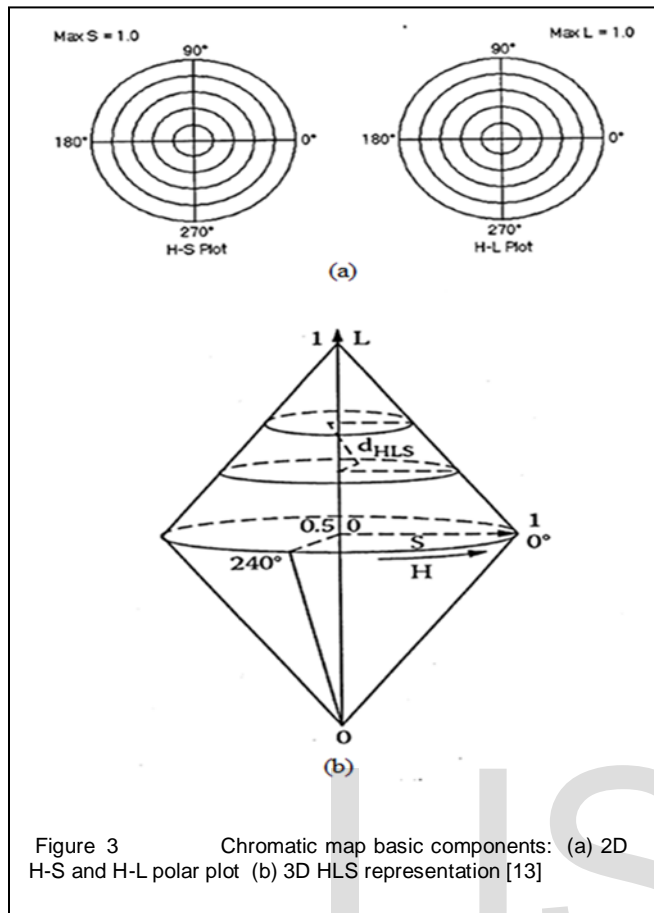
$$\text{If } G = min, \; H = 120 + 120 \times \left(\frac{b}{b+r}\right) \qquad (9)$$

$$\text{If } B = min, \; 240 + 120 \times \left(\frac{r}{r+g}\right) \qquad (10)$$

$$L = \frac{(R+G+B)}{3} \qquad (11)$$

$$S = \left(\frac{max - min}{max + min}\right) \qquad (12)$$

The latter are typically normalized to the range from 0 to 1. The signal can be represented by the coordinates H, L, S on two-dimensional chromatic maps in the form of H-S and H-L polar diagrams where H is the azimuthal angle, S or L is the radius with: H = θ [0°, 360°] and r = S or r = L from 0 to 1 as shown in Figure 3 (a). The H, L, S cordinates can also be represented in three dimensional space (θ, z, r) as shown in Figure 3 (b). On Figure 3 (a), the chromatic boundary encompassing all signals remains fixed as a circle of unity radius [12]. Physically, the radii on these diagrams represent the signal strength (L) or its spread (S). Thus, for the H-S curve, S=0 represents a signal spread across the, entire signal parameter range, whereas S = 1 represents a monochromatic signal. In the H - L diagram, L = 0 indicates a signal strength approaching zero. An important aspect of such signal representation on the chromatic maps is that the relationship between two signals is easily visualised and the superposition of two complex signals can be conveniently determined using simple moment equations.

Figure 3   Chromatic map basic components: (a) 2D H-S and H-L polar plot (b) 3D HLS representation [13]

Figure 4 CIE Diagram X:Y representation [17]

b)   Basic xyz transformation

An alternative transformation is the x, y, z transformation on which the CIE diagram of color science is based, Figure 4 [14]. The x, y, z are defined in terms of the outputs of the three chromatic processors R, G and B by the equations [15].

$$x = \frac{R_x}{R_x + G_y + B_z} \tag{13}$$

$$y = \frac{G_y}{R_x + G_y + B_z} \tag{14}$$

$$z = \frac{B_z}{R_x + G_y + B_z} \tag{15}$$

The CIE chromaticity diagram is a Cartesian representation in terms of x : y with z being implied via Equations (2.13-2.15) [11]. The diagram boundary represents maximum saturation for the spectral colors, and the diagram forms the boundary of all perceivable hues [16]. The x: y diagram thereby gives an indication of the relative contribution of each part of the signal covered by a chromatic processor (R, G or B) with respect to the other parts.

The monochromatic signals lie on the periphery of the color space defining curve of Figure 4. The point corresponding to R=G = B (i.e. S = 0 in HLS space) has coordinates (0.33, 0.33) in the xyz system (Figure 4).
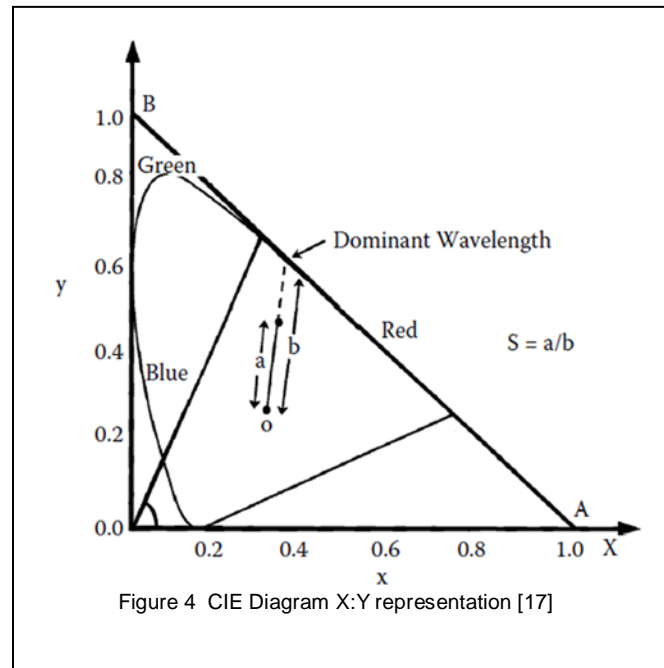
5   CONCLUSION

We have sought to explain the generic roots of chromatic modulation in terms of Gabor Transforms and to indicate consequentially how the approach may be deployedmore widely than simply for monitoring changes in the spectrum of polychromaticoptical signals. Examples of such a breadth of applications have been presented toillustrate the potential of the method.

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