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Full-color Gamut Mixing Model Constructed by Four-color Fibers and Spinning of Rotor-color Yarn

Wang Yanyan[1]*, Xue Yuan[1], Chen Yourong[2] and Chen Guofang[2]

[1]Department of Textile Science and Engineering, Jiangnan University, Wuxi 214000, China
[2]Department of Textile Science and Engineering, Zhejiang Taitan Co., Ltd, Shaoxing 311800, China

Abstract

Using three kinds of colored fiber and one kind of gray fiber as raw materials, a four-primary-color coupling-superposition color mixing model is constructed by the method of coupling and superposition based on the color mixing model, color change can be controlled in the range of panchromatic gamut, and the digital precision control of hue, brightness, and chrominance can be realized. Based on the three-channel NC spinning principle, the three-channel spinning mechanism of multi-channel feeding speed ratio, primary color fiber mixing ratio, and forming yarn color was established. One hundred fifty-six colors of three series of the same brightness but different hue; same hue but different brightness; and same hue but different chrominance are selected from the full-gamut color mixing model for spinning yarn and fabric; then list the HSL values of blended yarn, the technological feasibility of producing color yarn based on full-color gamut mixing model and three-channel CNC rotor spinning platform is verified.

Keywords: Colored yarn • Full-color gamut mixing model • Rotor spinning • Fiber color mixing • Color control • CNC spinning

Introduction

It is a popular textile production process that uses dyed fibers, stock dyed fibers, and naturally colored fibers to produce yarns with specific colors through the spinning process and then to produce colored fabrics and yarn-dyed garments through the weaving process. Mixing fibers of different colors to make color spinning generates a new color effect of color blending yarn using color space juxtaposition. The color mixing effect formed by this spatial juxtaposition and mixing will produce color fusion or separation in the observer's vision and form a dynamic color perception with the influence of factors such as distance, angle size, and ambient light changes. Compared with yarn dyeing and fabric dyeing, the colored spinning process has the following advantages: Environmental protection: the production process of dyed yarn before spinning, which saves water and reduces emissions by more than 50% compared with the traditional method, meets the requirements of low-carbon environmental protection; Fashion: Color-spinning is made by thoroughly mixing two or more fibers of different colors, showing multiple colors on the same yarn. It is a kind of yarn with rich, full, soft colors, unique color mixing effects, and color gradation. The woven fabric has a hazy three-dimensional effect, and the color is implicit, natural, and layered; Flexible processing: the color spinning process is flexible and easy to adjust colors, and it can better adapt to small batches and multiple varieties of production. The charm of color-spinning products is that the yarn and fabric are blended and spun into different colors. The color-space juxtaposition effect gives different visual effects to the yarn and fabric [1-3].

In order to realize the upgrading of color spinning production technology 4, the following key technologies need to be solved: one is the uniform mixing of different color fibers; in order to achieve uniform mixing of different color fibers, color spinning mainly adopts three mixing processes. It is to weigh and mix the bulk fibers of different colors according to the preset proportion, then mix them in bulk fibers through the opening, cleaning, and opening processes. In the drawing stage, the pure color raw cotton sliver made of different color fibers is drawn and mixed according to the preset proportion. In the spinning stage, slivers of different colors are fed into the multi-channel electronic drafting (opening) mechanism for asynchronous drafting (opening) and blended according to the preset proportion. The second is how to construct the color mixing mode of the primary color fiber and the color mixing model of the panchromatic gamut; to construct the color mixing mode and color mixing model of the primary color fiber, we can optimize the selection of the primary color fiber system for color matching and plan its digital mixing mode, construct the full-gamut color mixing model and give its full-gamut chromatography. The third is configuring the color mixing equation and controlling the color difference in the full-color gamut color mixing space. To configure the color mixing equation and control the color difference based on the predetermined color, the color mixing equation and its color difference prediction model based on the predetermined color can be constructed using the grid point samples in the full-color gamut color mixing space through the neural network algorithm.

Based on the opportunities and challenges faced by color-spinning, our research group has invented a three-channel rotor spinning equipment in the early stage, which can feed three pieces of cooked cotton slivers of different colors into the opening roller at different speeds, adjust the mixing ratio of the three primary colors through the change of the feeding rate, and then adjust the color of the formed yarn through the change of the mixing ratio of the three primary colors. Finally, the spinning process of full-gamut color yarn is studied through the constructed blending ratio and color control mechanism.

Firstly, this paper constructs the four-primary fiber gridding color mixing mode and the panchromatic color mixing model and gives the matrix equation of the panchromatic primary fiber mixing ratio and color value, hoping to solve the problem of color regulation through the construction of the correlation model of the four-primary fiber mixing ratio and panchromatic color value; secondly, by constructing the control mechanism of "multi-channel feeding speed ratio - color fiber mixing ratio – the color of formed yarn" of three-channel CNC rotor spinning, the full-color gamut control of hue, lightness, and chromaticity of the formed yarn is realized, and the process method of spinning full-color gamut color yarn is given; finally, the process theory and practice of spinning full-color gamut color yarn on three-channel CNC rotor spinning machine are verified by spinning series yarn with different hue, lightness, and chromaticity [4-6].

***Address for Correspondence:** Wang Yanyan, Department of Textile Science and Engineering, Jiangnan University, Wuxi 214000, China, E-mail: 3503701548@qq.com*

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Materials and Methods

Construction of nonlinear ternary coupling- superposition color mixing mode and panchromatic color mixing model for four-primary color fibers

Preparation of four primary color fibers and obtaining their color values:

Select dyes (reactive dyes, acid dyes, disperse dyes, and other applicable dyes), and optimize the color tricolor dyes with high color yield, pure color, and uniform distribution in the color ring, for example, magenta, cyan, yellow, or red, green, blue, or red, yellow, and blue. Dye is the natural or chemical fiber that has undergone loosening, impurity removal, uniform mixing, refining, and bleaching, and optimizes the dyeing process to obtain the three groups of color fibers α, β, γ with the highest color purity as the three primary color fibers for color mixing. Take the neutral gray color value $C_o \quad C_o(127,127,127)$ as the benchmark to obtain gray fiber *O*. Weigh the weight of four primary color fibers α, β, γ, o are $W_\alpha, W_\beta, W_\gamma, W_o$ respectively. The RGB color values of the four primary color fibers obtained by the colorimeter are $C_\alpha = C_\alpha(r_\alpha, g_\alpha, b_\alpha)$, $C_\beta = C_\beta(r_\beta, g_\beta, b_\beta)$, $C_\gamma = C_\gamma(r_\gamma, g_\gamma, b_\gamma)$, $C_o \quad C_o(r_o, g_o, b_o)$ [7].

Construction of nonlinear ternary coupling- superposition color mixing mode for four-primary color fibers

Design of discrete weight of four-color fiber: The weight of the above three-color fibers is treated with $1/n$ as the discretization gradient, and the weight of gray fibers is treated with $(i-1)/5/(m+1-i)$ as the nonlinear discretization gradient. The discretization weights of the four primary color fibers are obtained as follows:

$$\begin{cases} W_o(i) = W_o \times (i-1)/5/(m+1-i) \\ W_\alpha(j) = W_\alpha \times (j-1)/n \\ W_\beta(j) = W_\beta \times (j-1)/n \\ W_\gamma(j) = W_\gamma \times (j-1)/n \end{cases}$$

$$\begin{pmatrix} i = 1,2,3,\cdots,m,m+1 \\ j = 1,2,3,\cdots,n,n+1 \end{pmatrix} \quad (1)$$

Construction of nonlinear ternary combination color mixing mode of four primary color fibers: The above method can obtain four primary colors, and the hue, lightness, and chromaticity can be controlled by mixing the four primary colors. Select $W_o(j_1) - W_\alpha(j_2) - W_\beta(j_3)$, $W_o(j_1) - W_\beta(j_2) - W_\gamma(j_3)$, $W_o(j_1) - W_\gamma(j_2) - W_\alpha(j_3)$ for ternary combination color mixing, and the weight of each sub-sample is $W_{o\beta\alpha}(j_1, j_2, j_3)$, $W_{o\gamma\beta}(j_1, j_2, j_3)$, $W_{o\alpha\gamma}(j_1, j_2, j_3)$.

$$\begin{cases} W_{o\alpha\beta}(j_1,j_2,j_3) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\alpha + \dfrac{(j_3-1)}{n} \times W_\beta \\ W_{o\beta\gamma}(j_1,j_2,j_3) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\beta + \dfrac{(j_3-1)}{n} \times W_\gamma \\ W_{o\gamma\alpha}(j_1,j_2,j_3) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\gamma + \dfrac{(j_3-1)}{n} \times W_\alpha \end{cases}$$

$$\begin{pmatrix} j_1 = 1,2,3,\cdots,m,m+1 \\ j_2 = 1,2,3,\cdots,n,n+1 \\ j_3 = 1,2,3,\cdots,n,n+1 \end{pmatrix} \quad (2)$$

Construction of nonlinear ternary coupling and superposition color mixing mode for four-primary color fibers: Coupled-superimposed color mixing combines two or more color fibers with discrete weights. Suppose that the reference weight of each primary color fiber is equal, discrete the reference weight of each primary color fiber with an equal discrete number, and then select one part from the discrete weight sequence of each primary color fiber to combine to obtain a serialized color mixing sample. Suppose only the combination that can make the weight of the combined color mixing sample equal to the reference weight is selected. In that case, this combined color mixing method can be called coupling-superposition color mixing [8]. For the three primary color fibers, three primary color fibers can be discretized according to the same reference weight and the same discrete number, and the fibers of two primary colors can be selected for coupling color mixing. Then they can be superimposed with the third primary color fibers for color mixing. During the color mixing process, the sum of the weight of each color mixing sample is equal to the reference weight, and the mixing ratio of each primary color fiber changes in a gradient range of 0% to 100%; this mixing method is called coupling - superposition color mixing. For example, keep the mixing weight of $W_\alpha + W_\beta$ constant to form the first coupled color mixing, and then form the second coupled - superimposed color mixing with W_o coupled - superimposed color mixing, thus forming the ternary coupled-superimposed color mixing [9,10].

Based on the definition of coupling- superposition color mixing, suppose equation (2), $j_2 = j_3$; $W_{o\alpha\beta}(j_1, j_2, j_3) = W_{o\beta\gamma}(j_1, j_2, j_3) = W_{o\gamma\alpha}(j_1, j_2, j_3) = W$; $W_\alpha = W_\beta = W_\gamma = W_o = W$, The weight of each sub-sample of ternary coupling - superposition color mixing is as follows:

$$\begin{cases} W_{o\alpha\beta}(j_1,j_2) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\alpha + \dfrac{(j_2-1)}{n} \times W_\beta \\ W_{o\beta\gamma}(j_1,j_2) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\beta + \dfrac{(j_2-1)}{n} \times W_\gamma \\ W_{o\gamma\alpha}(j_1,j_2) = \dfrac{j_1-1}{5(m+1-j_1)} \times W_o + \dfrac{(n+1-j_2)}{n} \times W_\gamma + \dfrac{(j_2-1)}{n} \times W_\alpha \end{cases}$$

$$\begin{pmatrix} j_1 = 1,2,3,\cdots,m,m+1; \\ j_2 = 1,2,3,\cdots,n,n+1 \end{pmatrix} \quad (3)$$

Or write as:

$$\left[W_{o\alpha\beta}(j_1,j_2)\right] = \begin{bmatrix} W_{o\alpha\beta}(m+1,1) & W_{o\alpha\beta}(m+1,2) & \dots & W_{o\alpha\beta}(m+1,j_2) & \dots & W_{o\alpha\beta}(m+1,n) & W_{o\alpha\beta}(m+1,n+1) \\ W_{o\alpha\beta}(m,1) & W_{o\alpha\beta}(m,2) & \dots & W_{o\alpha\beta}(m-1,j_2) & \dots & W_{o\alpha\beta}(m-1,n) & W_{o\alpha\beta}(m,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\alpha\beta}(j_1,1) & W_{o\alpha\beta}(j_1,2) & \dots & W_{o\alpha\beta}(j_1,j_2) & \dots & W_{o\alpha\beta}(j_1,n) & W_{o\alpha\beta}(j_1,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\alpha\beta}(2,1) & W_{o\alpha\beta}(1,2) & \dots & W_{o\alpha\beta}(2,j_2) & \dots & W_{o\alpha\beta}(2,n) & W_{o\alpha\beta}(2,n+1) \\ W_{o\alpha\beta}(1,1) & W_{o\alpha\beta}(1,2) & \dots & W_{o\alpha\beta}(1,j_2) & \dots & W_{o\alpha\beta}(1,n) & W_{o\alpha\beta}(1,n+1) \end{bmatrix}_{m\times} \quad (4)$$

$$\left[W_{o\beta\gamma}(j_1,j_2)\right] = \begin{bmatrix} W_{o\beta\gamma}(m+1,1) & W_{o\beta\gamma}(m+1,2) & \dots & W_{o\beta\gamma}(m+1,j_2) & \dots & W_{o\beta\gamma}(m+1,n) & W_{o\beta\gamma}(m+1,n+1) \\ W_{o\beta\gamma}(m,1) & W_{o\beta\gamma}(m,2) & \dots & W_{o\beta\gamma}(m-1,j_2) & \dots & W_{o\beta\gamma}(m-1,n) & W_{o\beta\gamma}(m,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\beta\gamma}(j_1,1) & W_{o\beta\gamma}(j_1,2) & \dots & W_{o\beta\gamma}(j_1,j_2) & \dots & W_{o\beta\gamma}(j_1,n) & W_{o\beta\gamma}(j_1,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\beta\gamma}(2,1) & W_{o\beta\gamma}(1,2) & \dots & W_{o\beta\gamma}(2,j_2) & \dots & W_{o\beta\gamma}(2,n) & W_{o\beta\gamma}(2,n+1) \\ W_{o\beta\gamma}(1,1) & W_{o\beta\gamma}(1,2) & \dots & W_{o\beta\gamma}(1,j_2) & \dots & W_{o\beta\gamma}(1,n) & W_{o\beta\gamma}(1,n+1) \end{bmatrix}_{m\times n} \quad (5)$$

$$\left[W_{o\gamma\alpha}(j_1,j_2)\right] = \begin{bmatrix} W_{o\gamma\alpha}(m+1,1) & W_{o\gamma\alpha}(m+1,2) & \dots & W_{o\gamma\alpha}(m+1,j_2) & \dots & W_{o\gamma\alpha}(m+1,n) & W_{o\gamma\alpha}(m+1,n+1) \\ W_{o\gamma\alpha}(m,1) & W_{o\gamma\alpha}(m,2) & \dots & W_{o\gamma\alpha}(m-1,j_2) & \dots & W_{o\gamma\alpha}(m-1,n) & W_{o\gamma\alpha}(m,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\gamma\alpha}(j_1,1) & W_{o\gamma\alpha}(j_1,2) & \dots & W_{o\gamma\alpha}(j_1,j_2) & \dots & W_{o\gamma\alpha}(j_1,n) & W_{o\gamma\alpha}(j_1,n+1) \\ \dots & \dots & \dots\ \dots & & \dots\ \dots & & \dots \\ W_{o\gamma\alpha}(2,1) & W_{o\gamma\alpha}(1,2) & \dots & W_{o\gamma\alpha}(2,j_2) & \dots & W_{o\gamma\alpha}(2,n) & W_{o\gamma\alpha}(2,n+1) \\ W_{o\gamma\alpha}(1,1) & W_{o\gamma\alpha}(1,2) & \dots & W_{o\gamma\alpha}(1,j_2) & \dots & W_{o\gamma\alpha}(1,n) & W_{o\gamma\alpha}(1,n+1) \end{bmatrix}_{m\times n} \quad (6)$$

Let the mixing ratio of primary color fiber α, β, γ, o in the mixed sample be $\lambda_\alpha(j_1, j_2)$, $\lambda_\beta(j_1, j_2)$, $\lambda_\gamma(j_1, j_2)$, $\lambda_o(j_1, j_2)$; $j_1 = 1,2,3,\cdots,m,m+1$; $j_2 = 1,2,3,\cdots,n,n+1$. Then it can be obtained from equation (3):

For $W_{o\alpha\beta}(j_1, j_2)$, there is the following equation:

$$\begin{cases} \lambda_o(j_1,j_2) = \dfrac{j_1-1}{5m-4j_1+4} \\ \lambda_\alpha(j_1,j_2) = \dfrac{5(m+1-j_1)(n+1-j_2)}{n(5m-4j_1+4)} \\ \lambda_\beta(j_1,j_2) = \dfrac{5(m+1-j_1)(j_2-1)}{n(5m-4j_1+4)} \end{cases} \quad (7)$$

For $W_{\beta\gamma}(j_1, j_2)$, there is the following equation:

$$\begin{cases} \lambda_o(j_1,j_2) = \dfrac{j_1-1}{5m-4j_1+4} \\ \lambda_\beta(j_1,j_2) = \dfrac{5(m+1-j_1)(n+1-j_2)}{n(5m-4j_1+4)} \\ \lambda_\gamma(j_1,j_2) = \dfrac{5(m+1-j_1)(j_2-1)}{n(5m-4j_1+4)} \end{cases} \quad (8)$$

For $W_{o\gamma\alpha}(j_1,j_2)$, there is the following equation:

$$\begin{cases} \lambda_o(j_1,j_2)=\dfrac{j_1-1}{5m-4j_1+4} \\ \lambda_\gamma(j_1,j_2)=\dfrac{5(m+1-j_1)(n+1-j_2)}{n(5m-4j_1+4)} \\ \lambda_\alpha(j_1,j_2)=\dfrac{5(m+1-j_1)(j_2-1)}{n(5m-4j_1+4)} \end{cases} \tag{9}$$

If the color value of each mixed sub-sample in $W_{o\alpha\beta}(j_1,j_2)$, $W_{o\beta\gamma}(j_1,j_2)$, $W_{o\gamma\alpha}(j_1,j_2)$ is $C_{o\alpha\beta}(j_1,j_2)$, $C_{o\beta\gamma}(j_1,j_2)$, $C_{o\gamma\alpha}(j_1,j_2)$, then:

$$C_{o\alpha\beta}(j_1,j_2)=\begin{bmatrix} C_r(j_1,j_2) \\ C_g(j_1,j_2) \\ C_b(j_1,j_2) \end{bmatrix}=\begin{bmatrix} r_o & r_\alpha & r_\beta \\ g_o & g_\alpha & g_\beta \\ b_o & b_\alpha & b_\beta \end{bmatrix}\begin{bmatrix} \lambda_o(j_1,j_2) \\ \lambda_\alpha(j_1,j_2) \\ \lambda_\beta(j_1,j_2) \end{bmatrix}$$

$$\begin{pmatrix} j_1=1,2,3,\cdots,m,m+1 \\ j_2=1,2,3,\cdots,n,n+1 \end{pmatrix} \tag{10}$$

$$C_{o\beta\gamma}(j_1,j_2)=\begin{bmatrix} C_r(j_1,j_2) \\ C_g(j_1,j_2) \\ C_b(j_1,j_2) \end{bmatrix}=\begin{bmatrix} r_o & r_\beta & r_\gamma \\ g_o & g_\beta & g_\gamma \\ b_o & b_\beta & b_\gamma \end{bmatrix}\begin{bmatrix} \lambda_o(j_1,j_2) \\ \lambda_\alpha(j_1,j_2) \\ \lambda_\beta(j_1,j_2) \end{bmatrix}$$

$$\begin{pmatrix} j_1=1,2,3,\cdots,m,m+1 \\ j_2=1,2,3,\cdots,n,n+1 \end{pmatrix} \tag{11}$$

$$C_{o\gamma\alpha}(j_1,j_2)=\begin{bmatrix} C_r(j_1,j_2) \\ C_g(j_1,j_2) \\ C_b(j_1,j_2) \end{bmatrix}=\begin{bmatrix} r_o & r_\gamma & r_\alpha \\ g_o & g_\gamma & g_\alpha \\ b_o & b_\gamma & b_\alpha \end{bmatrix}\begin{bmatrix} \lambda_o(j_1,j_2) \\ \lambda_\alpha(j_1,j_2) \\ \lambda_\beta(j_1,j_2) \end{bmatrix}$$

$$\begin{pmatrix} j_1=1,2,3,\cdots,m,m+1 \\ j_2=1,2,3,\cdots,n,n+1 \end{pmatrix} \tag{12}$$

Or write as:

$$\left[C_{o\alpha\beta}(j_1,j_2)\right]=\begin{bmatrix} C_{o\alpha\beta}(m+1,1) & C_{o\alpha\beta}(m+1,2) & \dots & C_{o\alpha\beta}(m+1,j_2) & \dots & C_{o\alpha\beta}(m+1,n) & C_{o\alpha\beta}(m+1,n+1) \\ C_{o\alpha\beta}(m,1) & C_{o\alpha\beta}(m,2) & \dots & C_{o\alpha\beta}(m,j_2) & \dots & C_{o\alpha\beta}(m,n) & C_{o\alpha\beta}(m,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\alpha\beta}(j_1,1) & C_{o\alpha\beta}(j_1,2) & \dots & C_{o\alpha\beta}(j_1,j_2) & \dots & C_{o\alpha\beta}(j_1,n) & C_{o\alpha\beta}(j_1,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\alpha\beta}(2,1) & C_{o\alpha\beta}(1,2) & \dots & C_{o\alpha\beta}(2,j_2) & \dots & C_{o\alpha\beta}(2,n) & C_{o\alpha\beta}(2,n+1) \\ C_{o\alpha\beta}(1,1) & C_{o\alpha\beta}(1,2) & \dots & C_{o\alpha\beta}(1,j_2) & \dots & C_{o\alpha\beta}(1,n) & C_{o\alpha\beta}(1,n+1) \end{bmatrix} \tag{13}$$

$$\left[C_{o\beta\gamma}(j_1,j_2)\right]=\begin{bmatrix} C_{o\beta\gamma}(m+1,1) & C_{o\beta\gamma}(m+1,2) & \dots & C_{o\beta\gamma}(m+1,j_2) & \dots & C_{o\beta\gamma}(m+1,n) & C_{o\beta\gamma}(m+1,n+1) \\ C_{o\beta\gamma}(m,1) & C_{o\beta\gamma}(m,2) & \dots & C_{o\beta\gamma}(m,j_2) & \dots & C_{o\beta\gamma}(m,n) & C_{o\beta\gamma}(m,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\beta\gamma}(j_1,1) & C_{o\beta\gamma}(j_1,2) & \dots & C_{o\beta\gamma}(j_1,j_2) & \dots & C_{o\beta\gamma}(j_1,n) & C_{o\beta\gamma}(j_1,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\beta\gamma}(2,1) & C_{o\beta\gamma}(1,2) & \dots & C_{o\beta\gamma}(2,j_2) & \dots & C_{o\beta\gamma}(2,n) & C_{o\beta\gamma}(2,n+1) \\ C_{o\beta\gamma}(1,1) & C_{o\beta\gamma}(1,2) & \dots & C_{o\beta\gamma}(1,j_2) & \dots & C_{o\beta\gamma}(1,n) & C_{o\beta\gamma}(1,n+1) \end{bmatrix} \tag{14}$$

$$\left[C_{o\gamma\alpha}(j_1,j_2)\right]=\begin{bmatrix} C_{o\gamma\alpha}(m+1,1) & C_{o\gamma\alpha}(m+1,2) & \dots & C_{o\gamma\alpha}(m+1,j_2) & \dots & C_{o\gamma\alpha}(m+1,n) & C_{o\gamma\alpha}(m+1,n+1) \\ C_{o\gamma\alpha}(m,1) & C_{o\gamma\alpha}(m,2) & \dots & C_{o\gamma\alpha}(m,j_2) & \dots & C_{o\gamma\alpha}(m,n) & C_{o\gamma\alpha}(m,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\gamma\alpha}(j_1,1) & C_{o\gamma\alpha}(j_1,2) & \dots & C_{o\gamma\alpha}(j_1,j_2) & \dots & C_{o\gamma\alpha}(j_1,n) & C_{o\gamma\alpha}(j_1,n+1) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{o\gamma\alpha}(2,1) & C_{o\gamma\alpha}(1,2) & \dots & C_{o\gamma\alpha}(2,j_2) & \dots & C_{o\gamma\alpha}(2,n) & C_{o\gamma\alpha}(2,n+1) \\ C_{o\gamma\alpha}(1,1) & C_{o\gamma\alpha}(1,2) & \dots & C_{o\gamma\alpha}(1,j_2) & \dots & C_{o\gamma\alpha}(1,n) & C_{o\gamma\alpha}(1,n+1) \end{bmatrix} \tag{15}$$

Construction of full-color gamut grid color mixing modeldisc preparation

Full gamut control of color: Based on color science and its chromatology theory, color includes three dimensions: hue, lightness, and chromaticity. For the hue element color model, the full gamut refers to the color space defined by the hue angle changing from 0 °C to 360 °C, the brightness changing from 0 to 1, and the chromaticity changing from 0 to 1; what is called full gamut control color generally refers to the color control within the gamut defined by hue, lightness, and chromaticity. In order to realize the expression of mixed color of color fibers, this paper starts from the color of four primary color fibers. It discusses the realizable color space, definition, and range by constructing the ternary coupling - superposition mixing mode of four primary color fibers. The $W_{o\alpha\beta}(j_1,j_2)$, $W_{o\beta\gamma}(j_1,j_2)$, $W_{o\gamma\alpha}(j_1,j_2)$ coupled - superimposed color mixing gridding models constructed above include (m+1) * (n+1) grid points. By changing the grid point coordinates, the mixing ratio of the four primary color fibers α,β,γ,o can be changed, and the change of color hue, brightness, and chromaticity can be adjusted within their respective color gamut. However, the above control belongs to local color gamut control and cannot control the hue, brightness, and chromaticity changes of color within the full-color gamut range. In order to control the color change within the full-color gamut and realize the accurate digital control of hue, brightness, and chroma, it is necessary to build a full-color gamut grid color mixing model [11].

To this end, the three gridded sub-models of $W_{o\alpha\beta}(j_1,j_2)$, $W_{o\beta\gamma}(j_1,j_2)$, $W_{o\gamma\alpha}(j_1,j_2)$ are spliced with each other to get a panchromatic color blending model $W_{o-\alpha\beta\gamma}$ constructed by four primary color fibers α,β,γ,o . Let its grid point color be represented $C(j_1,\delta)$, and, $j_1=1,2,3,\cdots,m,m+1$; $\delta=1,2,3,\cdots,n-1,n,n+1,n+2,...,2n-1,2n,2n+1,...,3n-1,3n$,by changing the mixing ratio of the four primary color fibers α,β,γ,o of $C(j_1,\delta)$, the hue, lightness, and chromaticity of the color can be uniformly controlled within the full color gamut of $\alpha-\beta-\gamma-o$. To this end, the full-color gamut ternary coupling - superposition color mixing model $W_{o-\alpha\beta\gamma}$ is constructed, and the color values of each color mixing sample are as follows:

$$C(j_1,\delta)=C_o\times\varphi_o(j_1,\delta)+C_x\times\varphi_x(j_1,\delta)+C_y\times\varphi_y(j_1,\delta)$$

$$\begin{cases} j_1=1,2,3,\cdots,m,m+1 \\ \delta=1,2,3,\cdots,3n-1,3n \end{cases} \tag{16}$$

Among: $$C_x=\begin{cases} C_\alpha;\delta=1,2,\cdots,n-1,n \\ C_\beta;\delta=n+1,n+2,\cdots,2n-1,2n \\ C_\gamma;\delta=2n+1,2n+2,\cdots,3n-1,3n \end{cases} \tag{17}$$

$$C_y=\begin{cases} C_\beta;\delta=1,2,\cdots,n-1,n \\ C_\gamma;\delta=n+1,n+2,\cdots,2n-1,2n \\ C_\alpha;\delta=2n+1,2n+2,\cdots,3n-1,3n \end{cases} \tag{18}$$

From this, the color matrix of all subsamples of the panchromatic gamut gridded color mixing model is:

$$\left[C(j_1,\delta)\right]=\begin{bmatrix} C(m+1,1) & C(m+1,2) & \dots & C(m+1,\delta) & \dots & C(m+1,3n-1) & C(m+1,3n) \\ C(m,1) & C(m,2) & \dots & C(m-1,\delta) & \dots & C(m-1,3n-1) & C(m,3n) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C(j_1,1) & C(j_1,2) & \dots & C(j_1,\delta) & \dots & C(j_1,3n-1) & C(j_1,3n) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C(2,1) & C(1,2) & \dots & C(2,\delta) & \dots & C(2,3n-1) & C(2,3n) \\ C(1,1) & C(1,2) & \dots & C(1,\delta) & \dots & C(1,3n-1) & C(1,3n) \end{bmatrix}_{(m+1)\times 3n} \tag{19}$$

Substitute Equation (7) (8) (9) into Equation (16) to obtain the color mixing ratio of the full gamut model:

$$\varphi_o(j_1,\delta)=\frac{j_1-1}{5m-4j_1+4};\begin{cases} \delta=1,2,\cdots,3n-1,3n \\ j_1=1,2,\cdots,m,m+1 \end{cases} \tag{20}$$

$$\varphi_x(j_1,\delta)=\begin{cases} \dfrac{5(m+1-j_1)(n+1-j_2)}{n(5m-4j_1+4)};\begin{cases} \delta=1,2,\cdots,n-1,n \\ j_1=1,2,\cdots,m,m+1 \end{cases} \\ \dfrac{5(m+1-j_1)(j_2-1)}{n(5m-4j_1+4)};\begin{cases} \delta=n+1,n+2,\cdots,2n-1,2n \\ j_1=1,2,3,\cdots,m,m+1 \end{cases} \\ \dfrac{j_1-1}{5m-4j_1+4};\begin{cases} \delta=2n+1,2n+2,\cdots,3n-1,3n \\ j_1=1,2,\cdots,m,m+1 \end{cases} \end{cases} \tag{21}$$

$$\varphi_y(j_1,\delta)=\begin{cases} \dfrac{5(m+1-j_1)(j_2-1)}{n(5m-4j_1+4)};\begin{cases} \delta=1,2,\cdots,n-1,n \\ j_1=1,2,\cdots,m,m+1 \end{cases} \\ \dfrac{j_1-1}{5m-4j_1+4};\begin{cases} \delta=n+1,n+2,\cdots,2n-1,2n \\ j_1=1,2,3,\cdots,m,m+1 \end{cases} \\ \dfrac{5(m+1-j_1)(n+1-j_2)}{n(5m-4j_1+4)};\begin{cases} \delta=2n+1,2n+2,\cdots,3n-1,3n \\ j_1=1,2,\cdots,m,m+1 \end{cases} \end{cases} \tag{22}$$

Let the mixing ratio of each primary color fiber of the mixed sample of the full-gamut color mixing model be: $\varphi(j_1,\delta)=\left[\varphi_o(j_1,\delta) \quad \varphi_x(j_1,\delta) \quad \varphi_y(j_1,\delta)\right]^T$; from this, the blending ratio matrix of the panchromatic gamut gridded color mixing model is:

$$[\varphi(j_1,\delta)]=\begin{bmatrix} \varphi(m+1,1) & \varphi(m+1,2) & \dots & \varphi(m+1,\delta) & \dots & \varphi(m+1,3n-1) & \varphi(m+1,3n) \\ \varphi(m,1) & \varphi(m,2) & \dots & \varphi(m-1,\delta) & \dots & \varphi(m-1,3n-1) & \varphi(m,3n) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \varphi(j_1,1) & \varphi(j_1,2) & \dots & \varphi(j_1,\delta) & \dots & \varphi(j_1,3n-1) & \varphi(j_1,3n) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \varphi(2,1) & \varphi(1,2) & \dots & \varphi(2,\delta) & \dots & \varphi(2,3n-1) & \varphi(2,3n) \\ \varphi(1,1) & \varphi(1,2) & \dots & \varphi(1,\delta) & \dots & \varphi(1,3n-1) & \varphi(1,3n) \end{bmatrix}_{(m+1)\times 3n} \tag{23}$$

$j_1=1,2,3,\cdots,m,m+1;\delta=1,2,3,\cdots,3n-1,3n$ t

The color mixing model of the panchromatic gamut color mixing model $W_{o-\alpha\beta\gamma}$ corresponding to equation (19) is shown in (Figures 1 and 2).

Construction of circular full-color gamut grid color model: The full-color gamut gridded color model based on the ternary coupling - superposition color mixing of four primary color combinations has a total of 11 rows of 330 grid points, which are twisted into concentric circles to build the full-color gamut gridded ring color model. Let the coordinates of each grid point in the ring color model be: the polar angle is $\theta(\delta)$, and the polar radius is $\rho(j_1)$. Then the polar coordinates of each grid point position are:

$$\begin{cases} \theta(\delta)=\dfrac{2\pi\times(\delta-1)}{30} \\ \rho(j_1)=\rho\times(j_1-1)/10 \end{cases} \tag{24}$$

$j_1=1,2,\cdots,9,10,11$, $\delta=1,2,\cdots,30$

The rectangular panchromatic gamut gridding model with 330 grid points shown in Figure 2 is transformed into a circular panchromatic gamut gridding model, as shown in Figure 3. The change of hue from $\alpha\Leftrightarrow\beta\Leftrightarrow\gamma\Leftrightarrow\alpha$ is represented along the circumference, the change of brightness is reflected along the $o\alpha, o\beta, o\gamma$ radius directions, and the change of chromaticity is reflected along the other radius directions [12].

If the four primary colors are $C_\alpha=C_\alpha(0,255,255)$, $C_\beta=C_\beta(255,0,255)$, $C_\gamma=C_\gamma(255,255,0)$, $C_o=C_o(128,128,128)$, the ternary nonlinear coupling - superposition color mixing chromatogram of the four primary colors is shown in (Figures 3 and 4).

NC rotor spinning principle of full-color gamut yarn

Principle of three-channel CNC rotor spinning: CNC rotor spinning is a spinning method that is characterized by asynchronous drafting of multiple slivers (multiple channels) and can control the change of blended ratio, linear density, and the twist of the spun yarn online. For CNC spinning, a complete system includes a spinning mechanical system, a spinning control system, and a spinning servo system (Figures 5 and 6). Spinning mechanical system includes the multi-channel parallel coupling feeding mechanism, opening mechanism, rotor condensing mechanism, twisting mechanism, and winding forming mechanism of multi-channel coupling digital spinning machine; Spinning control system includes upper computer touch screen, lower computer PLC and control program; The spinning servo system consists of servo motor, variable frequency motor and its servo driver, frequency converter, encoder, reducer, etc. corresponding to each mechanism of the mechanical system [13].

Forming parameters of CNC rotor spinning: The linear density of the three primary-color cotton slivers fed through three channels[11] is ρ_0,ρ_x,ρ_y ($\rho_0=\rho_x=\rho_y=\rho$), the color is $C_o(R_o,G_o,B_o)$, $C_x(R_x,G_x,B_x)$, $C_y(R_y,G_y,B_y)$, the linear density after drawing by the middle roller is $\rho_{1o}(j_1,\delta)$, $\rho_{1x}(j_1,\delta)$, $\rho_{1y}(j_1,\delta)$, the linear density after drawing by the delivery roller is $\rho_{2o}(j_1,\delta)$, $\rho_{2x}(j_1,\delta)$, $\rho_{2y}(j_1,\delta)$, and the yarn with the linear density of $\rho_s(j_1,\delta)$ is combined, $\rho_s(j_1,\delta)=\rho_{2o}(j_1,\delta)+\rho_{2x}(j_1,\delta)+\rho_{2y}(j_1,\delta)$. If the linear speed of feeding roller o,x,y is V_0,V_x,V_y, the linear speed of middle roller is V_z, the rotational speed of opening roller is ω_1, the rotational speed of rotor is ω_2, the speed of drawing wire of delivery roller is V_s, and the blending ratio of three component fibers in spinning yarn is $\lambda_o(j_1,\delta)$, $\lambda_x(j_1,\delta)$, $\lambda_y(j_1,\delta)$ respectively, the following yarn forming parameters can be obtained.

Draft ratio at all levels of rotor spinning

First draft ratio: The draft ratio of the middle roller to the feeding roller o,x,y is called the first draft ratio. If the draft ratio of the middle roller to the cotton feeding roller o,x,y is $E_{1o}(j_1,\delta)$, $E_{1x}(j_1,\delta)$, $E_{1y}(j_1,\delta)$, then:

$$\begin{bmatrix} E_{1o}(j_1,\delta) \\ E_{1x}(j_1,\delta) \\ E_{1y}(j_1,\delta) \end{bmatrix}=\begin{bmatrix} V_z/V_0(j_1,\delta) \\ V_z/V_x(j_1,\delta) \\ V_z/V_y(j_1,\delta) \end{bmatrix} \tag{25}$$

Secondary draft ratio: The draft ratio of the delivery roller to the middle roller is called the secondary draft ratio of each channel. If the draft ratio of the

$C_{11,1}$	$C_{11,2}$	$C_{11,3}$	$C_{11,4}$	$C_{11,5}$	$C_{11,6}$	$C_{11,7}$	$C_{11,8}$	$C_{11,9}$	$C_{11,10}$	$C_{11,11}$	$C_{11,12}$	$C_{11,13}$	$C_{11,14}$	$C_{11,15}$	$C_{11,16}$	$C_{11,17}$	$C_{11,18}$	$C_{11,19}$	$C_{11,20}$	$C_{11,21}$	$C_{11,22}$	$C_{11,23}$	$C_{11,24}$	$C_{11,25}$	$C_{11,26}$	$C_{11,27}$	$C_{11,28}$	$C_{11,29}$	$C_{11,30}$
$C_{10,1}$	$C_{10,2}$	$C_{10,3}$	$C_{10,4}$	$C_{10,5}$	$C_{10,6}$	$C_{10,7}$	$C_{10,8}$	$C_{10,9}$	$C_{10,10}$	$C_{10,11}$	$C_{10,12}$	$C_{10,13}$	$C_{10,14}$	$C_{10,15}$	$C_{10,16}$	$C_{10,17}$	$C_{10,18}$	$C_{10,19}$	$C_{10,20}$	$C_{10,21}$	$C_{10,22}$	$C_{10,23}$	$C_{10,24}$	$C_{10,25}$	$C_{10,26}$	$C_{10,27}$	$C_{10,28}$	$C_{10,29}$	$C_{10,30}$
$C_{9,1}$	$C_{9,2}$	$C_{9,3}$	$C_{9,4}$	$C_{9,5}$	$C_{9,6}$	$C_{9,7}$	$C_{9,8}$	$C_{9,9}$	$C_{9,10}$	$C_{9,11}$	$C_{9,12}$	$C_{9,13}$	$C_{9,14}$	$C_{9,15}$	$C_{9,16}$	$C_{9,17}$	$C_{9,18}$	$C_{9,19}$	$C_{9,20}$	$C_{9,21}$	$C_{9,22}$	$C_{9,23}$	$C_{9,24}$	$C_{9,25}$	$C_{9,26}$	$C_{9,27}$	$C_{9,28}$	$C_{9,29}$	$C_{9,30}$
$C_{8,1}$	$C_{8,2}$	$C_{8,3}$	$C_{8,4}$	$C_{8,5}$	$C_{8,6}$	$C_{8,7}$	$C_{8,8}$	$C_{8,9}$	$C_{8,10}$	$C_{8,11}$	$C_{8,12}$	$C_{8,13}$	$C_{8,14}$	$C_{8,15}$	$C_{8,16}$	$C_{8,17}$	$C_{8,18}$	$C_{8,19}$	$C_{8,20}$	$C_{8,21}$	$C_{8,22}$	$C_{8,23}$	$C_{8,24}$	$C_{8,25}$	$C_{8,26}$	$C_{8,27}$	$C_{8,28}$	$C_{8,29}$	$C_{8,30}$
$C_{7,1}$	$C_{7,2}$	$C_{7,3}$	$C_{7,4}$	$C_{7,5}$	$C_{7,6}$	$C_{7,7}$	$C_{7,8}$	$C_{7,9}$	$C_{7,10}$	$C_{7,11}$	$C_{7,12}$	$C_{7,13}$	$C_{7,14}$	$C_{7,15}$	$C_{7,16}$	$C_{7,17}$	$C_{7,18}$	$C_{7,19}$	$C_{7,20}$	$C_{7,21}$	$C_{7,22}$	$C_{7,23}$	$C_{7,24}$	$C_{7,25}$	$C_{7,26}$	$C_{7,27}$	$C_{7,28}$	$C_{7,29}$	$C_{7,30}$
$C_{6,1}$	$C_{6,2}$	$C_{6,3}$	$C_{6,4}$	$C_{6,5}$	$C_{6,6}$	$C_{6,7}$	$C_{6,8}$	$C_{6,9}$	$C_{6,10}$	$C_{6,11}$	$C_{6,12}$	$C_{6,13}$	$C_{6,14}$	$C_{6,15}$	$C_{6,16}$	$C_{6,17}$	$C_{6,18}$	$C_{6,19}$	$C_{6,20}$	$C_{6,21}$	$C_{6,22}$	$C_{6,23}$	$C_{6,24}$	$C_{6,25}$	$C_{6,26}$	$C_{6,27}$	$C_{6,28}$	$C_{6,29}$	$C_{6,30}$
$C_{5,1}$	$C_{5,2}$	$C_{5,3}$	$C_{5,4}$	$C_{5,5}$	$C_{5,6}$	$C_{5,7}$	$C_{5,8}$	$C_{5,9}$	$C_{5,10}$	$C_{5,11}$	$C_{5,12}$	$C_{5,13}$	$C_{5,14}$	$C_{5,15}$	$C_{5,16}$	$C_{5,17}$	$C_{5,18}$	$C_{5,19}$	$C_{5,20}$	$C_{5,21}$	$C_{5,22}$	$C_{5,23}$	$C_{5,24}$	$C_{5,25}$	$C_{5,26}$	$C_{5,27}$	$C_{5,28}$	$C_{5,29}$	$C_{5,30}$
$C_{4,1}$	$C_{4,2}$	$C_{4,3}$	$C_{4,4}$	$C_{4,5}$	$C_{4,6}$	$C_{4,7}$	$C_{4,8}$	$C_{4,9}$	$C_{4,10}$	$C_{4,11}$	$C_{4,12}$	$C_{4,13}$	$C_{4,14}$	$C_{4,15}$	$C_{4,16}$	$C_{4,17}$	$C_{4,18}$	$C_{4,19}$	$C_{4,20}$	$C_{4,21}$	$C_{4,22}$	$C_{4,23}$	$C_{4,24}$	$C_{4,25}$	$C_{4,26}$	$C_{4,27}$	$C_{4,28}$	$C_{4,29}$	$C_{4,30}$
$C_{3,1}$	$C_{3,2}$	$C_{3,3}$	$C_{3,4}$	$C_{3,5}$	$C_{3,6}$	$C_{3,7}$	$C_{3,8}$	$C_{3,9}$	$C_{3,10}$	$C_{3,11}$	$C_{3,12}$	$C_{3,13}$	$C_{3,14}$	$C_{3,15}$	$C_{3,16}$	$C_{3,17}$	$C_{3,18}$	$C_{3,19}$	$C_{3,20}$	$C_{3,21}$	$C_{3,22}$	$C_{3,23}$	$C_{3,24}$	$C_{3,25}$	$C_{3,26}$	$C_{3,27}$	$C_{3,28}$	$C_{3,29}$	$C_{3,30}$
$C_{2,1}$	$C_{2,2}$	$C_{2,3}$	$C_{2,4}$	$C_{2,5}$	$C_{2,6}$	$C_{2,7}$	$C_{2,8}$	$C_{2,9}$	$C_{2,10}$	$C_{2,11}$	$C_{2,12}$	$C_{2,13}$	$C_{2,14}$	$C_{2,15}$	$C_{2,16}$	$C_{2,17}$	$C_{2,18}$	$C_{2,19}$	$C_{2,20}$	$C_{2,21}$	$C_{2,22}$	$C_{2,23}$	$C_{2,24}$	$C_{2,25}$	$C_{2,26}$	$C_{2,27}$	$C_{2,28}$	$C_{2,29}$	$C_{2,30}$
$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	$C_{1,4}$	$C_{1,5}$	$C_{1,6}$	$C_{1,7}$	$C_{1,8}$	$C_{1,9}$	$C_{1,10}$	$C_{1,11}$	$C_{1,12}$	$C_{1,13}$	$C_{1,14}$	$C_{1,15}$	$C_{1,16}$	$C_{1,17}$	$C_{1,18}$	$C_{1,19}$	$C_{1,20}$	$C_{1,21}$	$C_{1,22}$	$C_{1,23}$	$C_{1,24}$	$C_{1,25}$	$C_{1,26}$	$C_{1,27}$	$C_{1,28}$	$C_{1,29}$	$C_{1,30}$

Figure 1. The panchromatic gamut color mixing model constructed by ternary coupling and superposition color mixing.

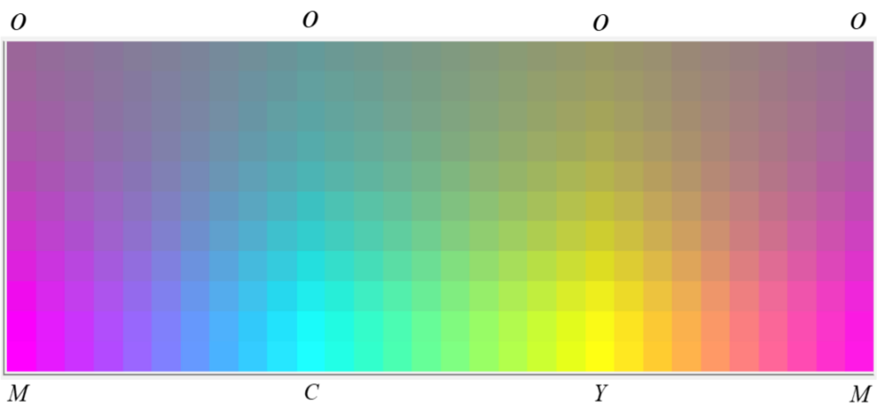

Figure 2. The color mixing chromatogram of the panchromatic gamut grid color mixing model.

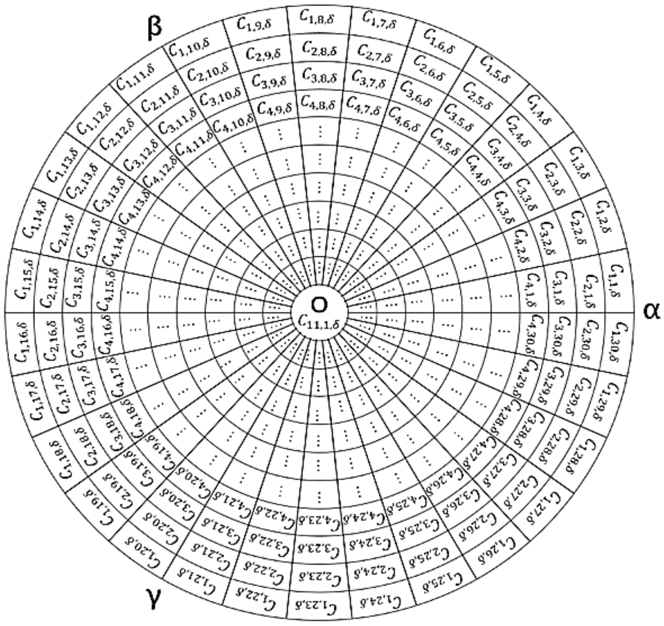

Figure 3. Circular full-color gamut grid color model.

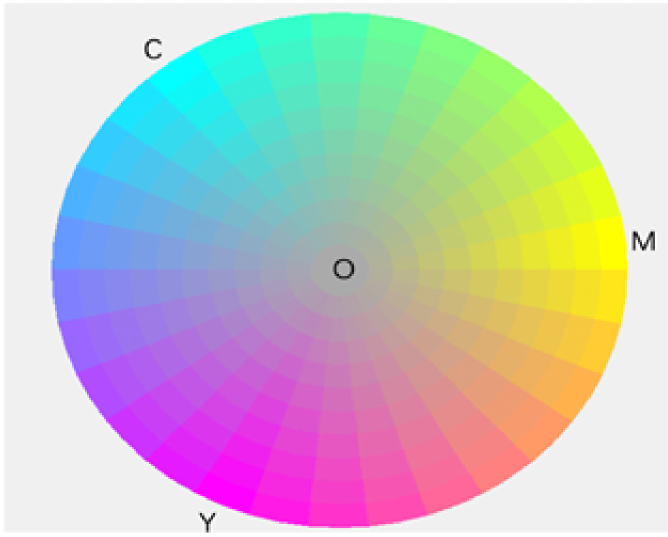

Figure 4. Color distribution diagram of circular full.

delivery roller to the middle roller is $E_2(j_1,\delta)$, then:

$$E_2(j_1,\delta)=V_s/V_z \tag{26}$$

Total draft ratio of each channel: The draft ratio of the yarn guide roller to the cotton feeding roller o,x,y of each channel is called the total draft ratio of each channel $E_o(j_1,\delta),E_x(j_1,\delta),E_y(j_1,\delta)$, then:

$$\begin{bmatrix} E_o(j_1,\delta) \\ E_x(j_1,\delta) \\ E_y(j_1,\delta) \end{bmatrix} = V_s \times \begin{bmatrix} 1/V_0(j_1,\delta) \\ 1/V_x(j_1,\delta) \\ 1/V_y(j_1,\delta) \end{bmatrix} \tag{27}$$

Linear density of yarn:

$$\rho_s(j_1,\delta) = \frac{\rho}{V_s} \times \begin{bmatrix} V_o(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} \tag{28}$$

Yarn blending ratio:

$$\begin{bmatrix} \lambda_o(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix} = \frac{\rho_0}{\rho_s(j_1,\delta)\times V_s} \times \begin{bmatrix} V_0(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} \tag{29}$$

Yarn color:

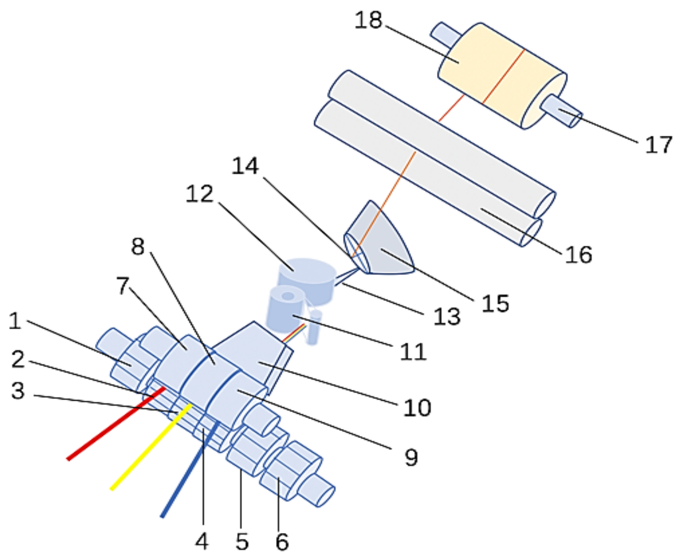

Figure 5. Three-channel CN Crotor spinning system.

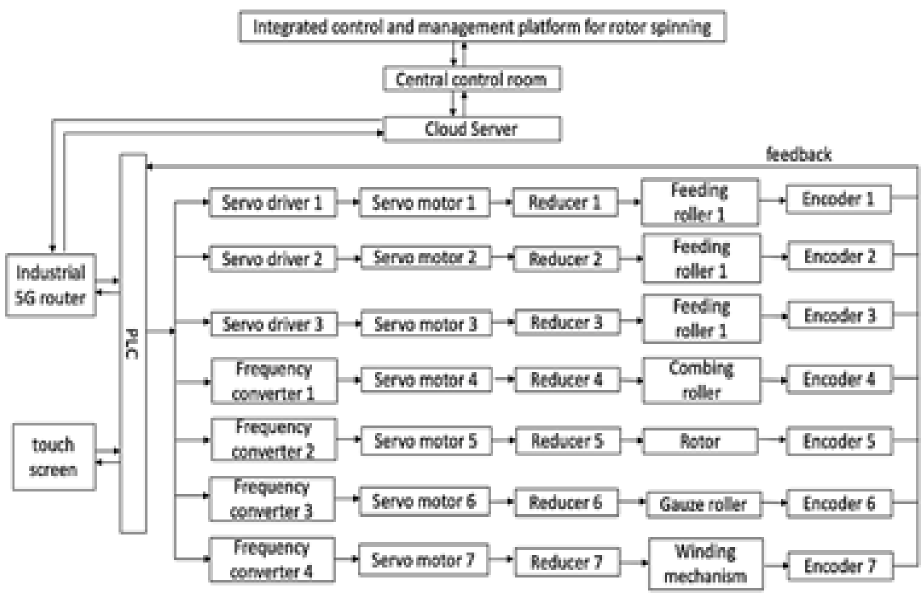

Figure 6. Servo drive and control system of three-channel CN Crotor spinning.

Suppose that the sliver color is $o(R_o, G_o, B_o)$, $x(R_x, G_x, B_x)$, $y(R_y, G_y, B_y)$, and the yarn is twisted according to the mixing ratio of $\lambda_o(j_1,\delta), \lambda_x(j_1,\delta), \lambda_y(j_1,\delta)$ after separation and drafting, the yarn color $C_s(j_1,\delta) = \left[C_r(j_1,\delta), C_g(j_1,\delta), C_b(j_1,\delta)\right]^t$ is:

$$C_s(j_1,\delta) = \begin{bmatrix} C_r(j_1,\delta) \\ C_g(j_1,\delta) \\ C_b(j_1,\delta) \end{bmatrix} = \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix} \begin{bmatrix} \lambda_0(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix}$$

$$= \frac{\rho_0}{\rho_s(j_1,\delta)\times V_s} \times \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix} \begin{bmatrix} V_o(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} \tag{30}$$

Yarn twist:

$$N_w = \omega_2 / V_s \tag{31}$$

Color control mechanism of rotor spinning yarn

Mechanism of yarn blending ratio and color control based on feeding roller speed:

$$\begin{bmatrix} \lambda_o(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix} = \frac{\rho}{\rho_s(i,j)\times V_s} \times \begin{bmatrix} V_0(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} \tag{32}$$

It can be seen from equation (32) that the yarn blending ratio can be adjusted by adjusting the speed of the feed roller wire $V_o(j_1,\delta), V_x(j_1,\delta), V_y(j_1,\delta)$.

$$C_s(j_1,\delta) = \begin{bmatrix} C_r(j_1,\delta) \\ C_g(j_1,\delta) \\ C_b(j_1,\delta) \end{bmatrix} = \frac{\rho_0}{\rho_s(j_1,\delta)\times V_s} \times \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix} \begin{bmatrix} V_o(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} \tag{33}$$

According to equation (33), the yarn color $C_s(j_1,\delta)$ can be adjusted by adjusting the linear speed $V_o(j_1,\delta), V_x(j_1,\delta), V_y(j_1,\delta)$ of the feeding roller [14-16].

Mechanism of adjusting yarn color and feeding roller speed based on blending ratio: It can be seen from equation (34) that the yarn color $C_s(j_1,\delta)$ can be adjusted by adjusting the yarn blending ratio $\lambda_o(j_1,\delta), \lambda_x(j_1,\delta), \lambda_y(j_1,\delta)$.

$$C_s(j_1,\delta) = \begin{bmatrix} C_r(j_1,\delta) \\ C_g(j_1,\delta) \\ C_b(j_1,\delta) \end{bmatrix} = \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix} \begin{bmatrix} \lambda_0(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix} \tag{34}$$

It can be seen from equation (35) that by adjusting the yarn blending ratio $\lambda_o(j_1,\delta), \lambda_x(j_1,\delta), \lambda_y(j_1,\delta)$, the feeding roller speed $V_o(j_1,\delta), V_x(j_1,\delta), V_y(j_1,\delta)$ can be adjusted.

$$\begin{bmatrix} V_0(j_1,\delta) \\ V_x(j_1,\delta) \\ V_y(j_1,\delta) \end{bmatrix} = \frac{\rho_s(i,j)\times V_s}{\rho} \times \begin{bmatrix} \lambda_o(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix} \tag{35}$$

Mechanism of adjusting blending ratio and feeding roller speed based on yarn color :

$$\begin{bmatrix} \lambda_0(j_1,\delta) \\ \lambda_x(j_1,\delta) \\ \lambda_y(j_1,\delta) \end{bmatrix} = \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix}^{-1} \times \begin{bmatrix} C_r(j_1,\delta) \\ C_g(j_1,\delta) \\ C_b(j_1,\delta) \end{bmatrix} \tag{36}$$

According to equation (36), the yarn blending ratio $\lambda_o(j_1,\delta), \lambda_x(j_1,\delta), \lambda_y(j_1,\delta)$ can be adjusted by adjusting the yarn color $C_s(j_1,\delta)$.

$$\begin{bmatrix} V_{0\alpha}(j_1,\delta) \\ V_{0\beta}(j_1,\delta) \\ V_{0\gamma}(j_1,\delta) \end{bmatrix} = \frac{\rho_s(j_1,\delta)\times V_s}{\rho} \begin{bmatrix} R_o & R_x & R_y \\ G_o & G_x & G_y \\ B_o & B_x & B_y \end{bmatrix}^{-1} \times \begin{bmatrix} C_r(j_1,\delta) \\ C_g(j_1,\delta) \\ C_b(j_1,\delta) \end{bmatrix} \tag{37}$$

It can be seen from equation (37) that the feed wire speed $V_o(j_1,\delta), V_x(j_1,\delta), V_y(j_1,\delta)$ can be adjusted by adjusting the yarn color $C_s(j_1,\delta)$.

From mechanism of yarn blending ratio and color control based on feeding roller speed to mechanism of adjusting blending ratio and feeding roller speed based on yarn colorit can be seen that the three-factor regulation mechanism of three-channel CNC spinning is shown in (Figure 7).

Construction of a three-channel rotor color spinning grid color mixing model and spinning of full-color gamut color yarn

Grid color mixing model constructed by three-channel rotor color spinning: Suppose $j_1 = 1,2,3,\cdots,10,11; \delta = 1,2,3,\cdots,29,30$, substitute the measured value of sliver color into equation (16) to obtain:

$$[C_s(j_1,\delta)] = \begin{bmatrix} C(11,1) & C(11,2) & \cdots & C(11,29) & C(11,30) \\ C(10,1) & C(10,2) & \cdots & C(10,29) & C(10,30) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C(2,1) & C(2,2) & \cdots & C(2,29) & C(2,30) \\ C(1,1) & C(1,2) & \cdots & C(1,29) & C(1,30) \end{bmatrix} \tag{40}$$

Draft ratio matrix of three-channel rotor color spinning: Based on the linear density of sliver and yarn, the blending ratio matrix, the draft ratio matrix can be obtained, and then the specific values can be substituted into:

$$E(j_1,\delta) = \begin{bmatrix} E(11,1) & E(11,2) & \cdots & E(11,29) & E(11,30) \\ E(10,1) & E(10,2) & \cdots & E(10,29) & E(10,30) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ E(2,1) & E(2,2) & \cdots & E(2,29) & E(2,30) \\ E(1,1) & E(1,2) & \cdots & E(1,29) & E(1,30) \end{bmatrix} \tag{41}$$

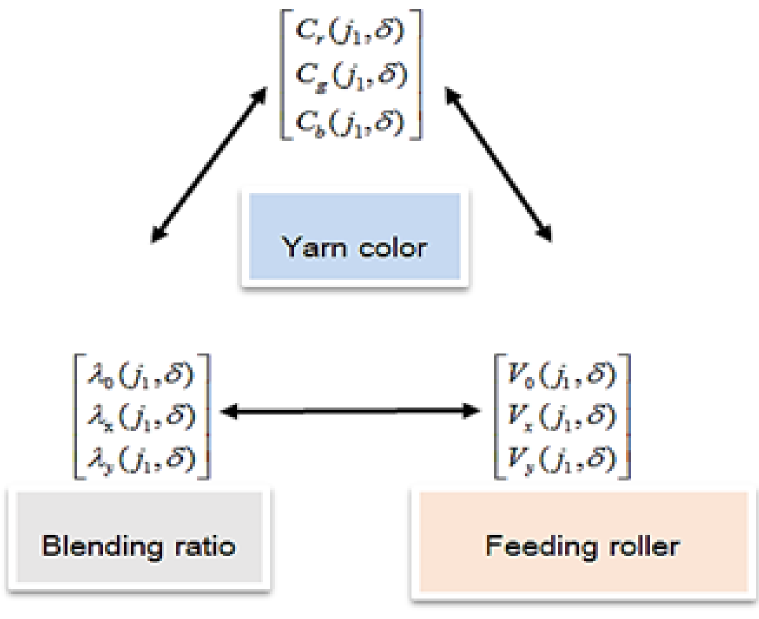

Figure 7. Three-element regulation mechanism of three-channel CNC spinning.

$j_1 = 1,2,3,\cdots,10,11; \delta = 1,2,3,\cdots,29,30$

Feeding roller speed matrix of three-channel rotor color spinning:

$$V(j_1,\delta)=\begin{bmatrix} V(11,1) & V(11,2) & \cdots & V(11,29) & V(11,30) \\ V(10,1) & V(10,2) & \cdots & V(10,29) & V(10,30) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ V(2,1) & V(2,2) & \cdots & V(2,29) & V(2,30) \\ V(1,1) & V(1,2) & \cdots & V(1,29) & V(1,30) \end{bmatrix} \quad (42)$$

$j_1 = 1,2,3,\cdots,10,11; \delta = 1,2,3,\cdots,29,30$

Spinning process design of full-gamut color yarn

Color value acquisition of four-color cotton sliver: The linear density of the prepared sliver is 450 g/km, and the color values of the four primary color fibers are measured with the Datacolor600 colorimeter under the standard light source, as shown in (Table 1).

Construction of full-gamut color mixing chromatography:

$$C_y(j_1,\delta)=\begin{bmatrix} C(11,1) & C(11,2) & \cdots & C(11,29) & C(11,30) \\ C(10,1) & C(10,2) & \cdots & C(10,29) & C(10,30) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C(2,1) & C(2,2) & \cdots & C(2,29) & C(2,30) \\ C(1,1) & C(1,2) & \cdots & C(1,29) & C(1,30) \end{bmatrix}$$

According to the color value and color value matrix of the four-color cotton sliver, the full-color gamut chromatogram is drawn as shown in (Figure 8).

Based on the gridded color mixing model constructed in Figure 3, the full-color gamut chromatogram in Figure 8 can be divided into three types of serial chromatograms: brightness unchanged, hue change; the hue remains unchanged and the chromaticity changes; the hue remains unchanged and the lightness changes.

The first type is 11 series chromatograms with constant brightness and hue change:

$$\left[C(i,1),C(i,2),...,C(i,29),C(i,30)\right];(i=1,2,\cdots,10,11)$$

The second type is 27 series chromatography with unchanged hue and changed chromaticity:

$$\left[C(1,i),C(2,i),...,C(10,i),C(11,i)\right];(i=1,2,\cdots,29,30; i\neq 1,11,21)$$

The third type is three series chromatography with unchanged hue and changed lightness:

$$\left[C(1,i),C(2,i),...,C(10,i),C(11,i)\right];(i=1,11,21)$$

Based on the above analysis, it can be seen that the hue, lightness, and chromaticity of yarn color can be adjusted and controlled through grid color mixing.

Table 1. The color value of four primary color cotton sliver.

Cotton sliver	Lab	RGB
Magenta (α)	(40.14, 60.22, 5.19)	(178, 28, 89)
cyan (β)	(49.93, -31.34, -25.75)	(0, 134, 162)
yellow(γ)	(82.04, 2.4, 86.51)	(238, 200, 0)
grey (o)	(93.13 ,0.2, 3.06)	(238, 235, 229)

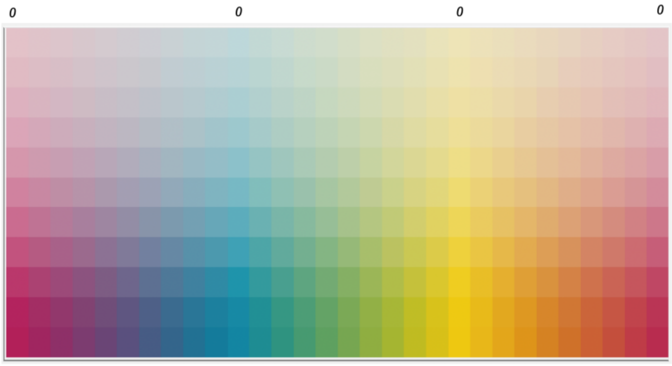

Figure 8. Panchromatic gamut chromatogram of four-primary color gridded color mixing.

Specification design of colored yarn: In order to verify the feasibility of the color yarn spinning process, we selected the mixed sample with grid point coordinate of $i=1,3,7;\delta=1,2,\cdots,29,30$ from the first type and spun a total of 90 yarn samples. The mixing ratio is calculated as follows:

Based on equation (20) (21) (22), let $m=n=10$, the mixture can be obtained, as shown in (Table 2).

According to its color value and blending ratio, the feeding roller speed can be obtained as shown in (Table 3).

Select the mixed sample with grid point coordinate of from the second type and spin a total of 33 yarn samples. Based on equation (20) (21) (22), let, and its mixture can be calculated as shown in (Table 4).

According to its color value and blending ratio, the feeding roller speed can be obtained as shown in (Table 5).

Table 2. Mixing ratio of the first type.

$C_{1,\delta}$ **Mixing Ratio**			$C_{3,\delta}$ **Mixing Ratio**			$C_{7,\delta}$ **Mixing Ratio**		
λ_o	λ	λ_y	λ_o	λ_x	λ_y	λ_o	λ_x	λ_y
0	10	90	5	10	85	23	8	69
0	20	80	5	19	76	23	15	62
0	30	70	5	29	66	23	23	54
0	40	60	5	38	57	23	31	46
0	50	50	5	48	47	23	38	39
0	60	40	5	57	38	23	46	31
0	70	30	5	67	28	23	54	23
0	80	20	5	76	19	23	62	15
0	90	10	5	86	9	23	69	8
0	100	0	5	95	0	23	77	0

Table 3. Three feeding roller speeds of the first type.

$C_{1,\delta}$ **Feeding Roller Speed (m/min)**			$C_{3,\delta}$ **Feeding Roller Speed (m/min)**			$C_{7,\delta}$ **Feeding Roller Speed (m/min)**		
V_o	V_x	V_y	V_x	V_x	V_y	V_o	V_x	V_y
0	0.24	2.16	0.12	0.22	2.06	0.55	0.19	1.66
0	0.48	1.92	0.12	0.46	1.82	0.55	0.36	1.49
0	0.72	1.68	0.12	0.67	1.61	0.55	0.55	1.3
0	0.96	1.44	0.12	0.91	1.37	0.55	0.74	1.1
0	1.2	1.2	0.12	1.15	1.13	0.55	0.91	0.94
0	1.44	0.96	0.12	1.37	0.91	0.55	1.1	0.74
0	1.68	0.72	0.12	1.61	0.67	0.55	1.3	0.55
0	1.92	0.48	0.12	1.82	0.46	0.55	1.49	0.36
0	2.16	0.24	0.12	2.06	0.22	0.55	1.66	0.19
0	2.4	0	0.12	2.28	0	0.55	1.85	0

Table 4. Mixing ratio of the second type.

Grid Point Coordinates (i=5,15,25)		$C_{1,i}$	$C_{2,i}$	$C_{3,i}$	$C_{4,i}$	$C_{5,i}$	$C_{6,i}$	$C_{7,i}$	$C_{8,i}$	$C_{9,i}$	$C_{10,i}$	$C_{11,i}$
	λ_o	0	2	5	8	12	17	23	32	44	64	100
Mixing Ratio	λ_x	60	59	57	55	53	50	46	41	33	21	0
	λ_y	40	39	38	37	35	33	31	27	23	15	0

Table 5. Three feeding roller speeds of the second type.

Grid Point Coordinates (i=5,15,25)		$C_{1,i}$	$C_{2,i}$	$C_{3,i}$	$C_{4,i}$	$C_{5,i}$	$C_{6,i}$	$C_{7,i}$	$C_{8,i}$	$C_{9,i}$	$C_{10,i}$	$C_{11,i}$
Feeding Roller Speed *(m/s)*	V_o	0	0.05	0.12	0.12	0.12	0.41	0.55	0.55	0.55	0.55	0.55
	V_x	1.44	1.42	1.37	1.37	1.37	1.2	1.1	1.1	1.1	1.1	1.1
	V_y	0.9	0.94	0.91	0.91	0.91	0.79	0.74	0.74	0.74	0.74	0.74

A total of 33 yarn samples were spun from the mixed sample of the third type grid point coordinate. Based on equation (20) (21) (22), let, and its mixture can be calculated as shown in (Table 6).

According to its color value and blending ratio, the feeding roller speed can be obtained as shown in (Table 7).

Design of spinning process parameters: Based on product requirements, the process design of rotor spinning is configured. 30tex pure cotton rotor spinning is designed with a twist coefficient of 430, the diameter of the rotary cup is 47mm, the model is 54 cups, and the opening roller rack model is OK40. The relevant process calculation is as follows:

- Sliver weight, yarn density, and twist

Select silver weight: 450 g/km, yarn density: 30tex, twist coefficient: 430 made of Teethe design twist (twist/10 cm) $=\text{Twist factor of linear density system} / \sqrt{T_t} = 430/\sqrt{30} = 78.5\,\text{twist}/10cm$ $=785\,\text{twist}/m$, corrected to 800 twist/m.

- Rotor speed, yarn drawing speed

Set the yarn drawing speed as: $V_y = 22m/\min$

Rotor speed: $\omega = N_w * V_y = 800 \times 22 = 17600\text{rpm}$

- Selection of speed and linear speed of opening roller

The linear speed of the opening roller is 6000 r/min.

The speed of the three rear feeding rollers and the speed of the middle

Table 6. Mixing ratio of the third type.

Grid Point Coordinates (i=5,15,25)		$C_{1,i}$	$C_{2,i}$	$C_{3,i}$	$C_{4,i}$	$C_{5,i}$	$C_{6,i}$	$C_{7,i}$	$C_{8,i}$	$C_{9,i}$	$C_{10,i}$	$C_{11,i}$
Mixing Ratio	λ_o	0	0	5	8	12	17	23	32	44	64	100
	λ_x	100	100	95	92	88	83	77	68	56	36	0
	λ_y	0	0	0	0	0	0	0	0	0	0	0

Table 7. Three feeding roller speeds of the third type.

Grid Point Coordinates ($i = 1, 11, 21$)		$C_{1,i}$	$C_{2,i}$	$C_{3,i}$	$C_{4,i}$	$C_{5,i}$	$C_{6,i}$	$C_{7,i}$	$C_{9,i}$	$C_{9,i}$	$C_{10,i}$	$C_{11,i}$
Feeding Roller Speed (m/s)	V_o	0	0.05	0.12	0.19	0.29	0.41	0.55	0.77	1.06	1.54	2.4
	V_x	2.4	2.35	2.28	2.21	2.11	1.99	1.85	1.63	1.34	0.86	0
	V_y	0	0	0	0	0	0	0	0	0	0	0

Table 8. Process design of 30 tex rotor yarn for knitting.

Process Parameters	To Configure
Density of design line (tex)	30
Twist (twist/10 cm)	80
Twist factor	430
Rotor speed (r/min)	17600
Opening roller speed (r/min)	6000
Output speed (m/min)	22
Coiling speed (m/min)	22.2
Winding factor	1.01
Cotton feeding factor	1.15

Figure 9. The first type of blended yarn.

feeding roller

$$\begin{bmatrix} V_{0\alpha}(j_1,\delta) \\ V_{0\beta}(j_1,\delta) \\ V_{0\gamma}(j_1,\delta) \end{bmatrix} = \frac{\rho_y(j_1,\delta)\times V_y}{\rho_0} \times \begin{bmatrix} \varphi_\alpha(j_1,\delta) \\ \varphi_\beta(j_1,\delta) \\ \varphi_\gamma(j_1,\delta) \end{bmatrix}$$

The specific process parameters of 30 tex rotor spinning for knitting are shown in (Table 8).

Results and Discussion

Experimental results

Blended yarn and its fabric: The blended yarn spun according to the set process parameters is shown in Figure 9, Figure 11, and Figure 13. The yarn is arranged in the order of three types of chromatography. The knitted fabric formed by the blended yarn is shown in figure 10, figure 12, and figure 14, and the arrangement order is the same as that of the blended yarn.

The first type: Brightness unchanged, hue change (Figures 9 and 10).

The second type: The hue remains unchanged, and the chromaticity changes (Figures 11-14).

Compare the pictures of three types of blended yarn and fabric with the chromatograms of three types, and the color change of blended yarn and fabric is consistent with the chromatogram in the series of chromaticity unchanged, hue change; the lightness changes of the blended yarn and fabric are consistent with the chromatogram in the series of the hue remains unchanged and the chromaticity changes; the chromaticity change of blended yarn and fabric is

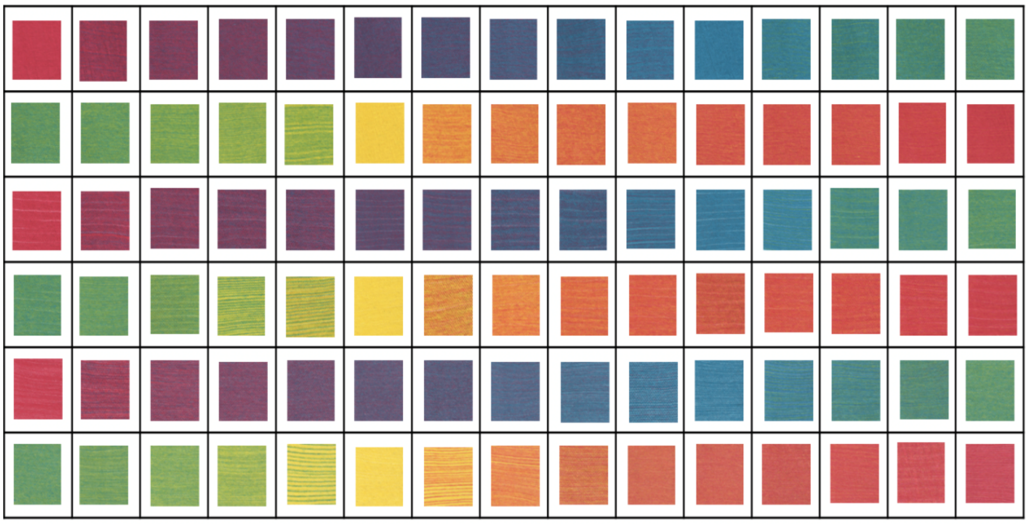

Figure 10. The first type of blended yarn knitted fabric.

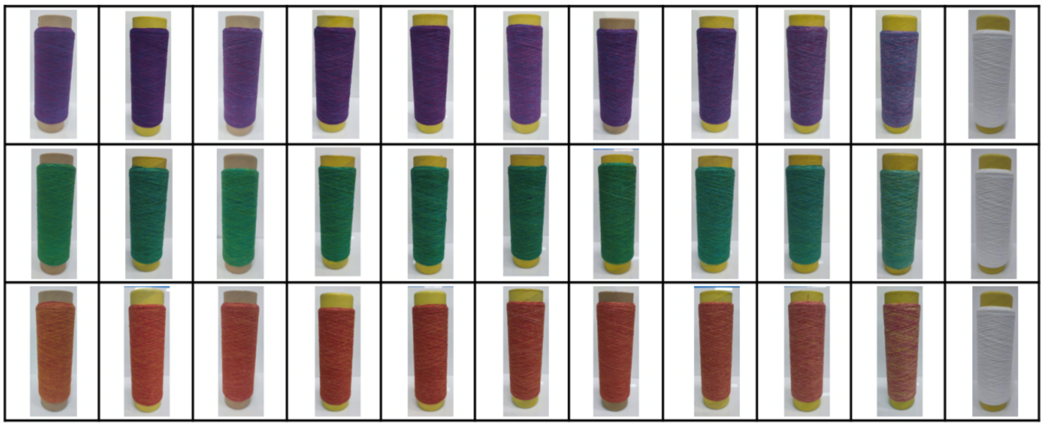

Figure 11. The second type of blended yarn.

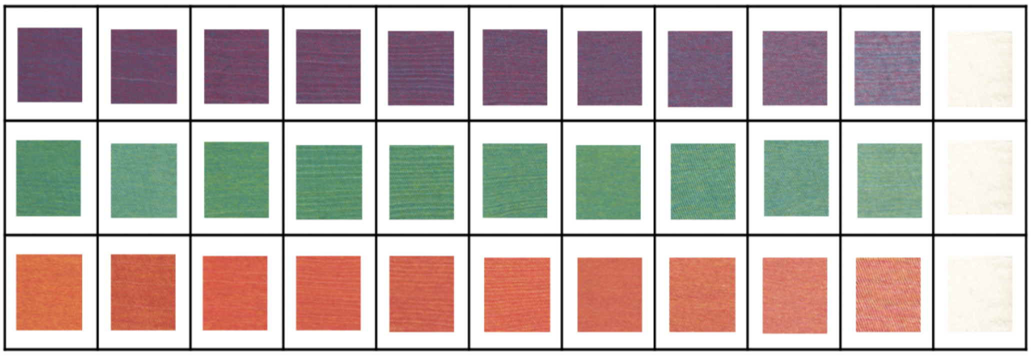

Figure 12. The second type of blended yarn knitted fabric.

consistent with the chromatogram in the series of the hue remains unchanged and the brightness changes; it can be found that the color change rule of the blended yarn and its fabric is consistent with the color change rule of the blended yarn chromatogram based on the full-color gamut grid color mixing model, which verifies the three-channel rotor spinning mechanism of the co-regulation of the draft ratio, the color mixing ratio and the yarn color.

Color difference of blended yarn: The $L^*a^*b^*$ value was measured using a Datacolor 650 spectrophotometer. Under a D65 light source and a 10 °C standard viewing angle, the test aperture was 30 mm, the wavelength range of the light source was 400-700 nm, and the sampling interval was 10 nm. To reduce experimental errors and improve the accuracy of the experiment, ensure that the surface of the fabric is flat and free from wrinkles during measurement, and fold the 156 types of knitted fabrics prepared to a certain thickness to ensure that the sample is not transparent during testing; For the same sample, randomly select 15 different parts for measurement, and take their mean as the final color measurement experimental data. Use the ColorTell color conversion tool to convert the $L^*a^*b^*$ values of three types of blended yarns into HSL values, as shown in Tables 9, 10, and 11, respectively.

The first type: Brightness unchanged, hue change (Table 9).

The second type: The hue remains unchanged, and the chromaticity changes (Table 10).

The third type: The hue remains unchanged, and the brightness changes (Table 11).

From the table, it can be seen that in the first type, the hue changes from 0 to 360 °C, and the hue change trend is consistent with the constructed full gamut color mixing model. In the second type, the hue remains basically unchanged, and the chromaticity change trend is consistent with the constructed full gamut color mixing model. In the third type, the hue remains basically unchanged, and the brightness change trend is consistent with the constructed full gamut color mixing model. The feasibility of spinning full color gamut blended yarn using the constructed full color gamut grid blended model was once again verified.

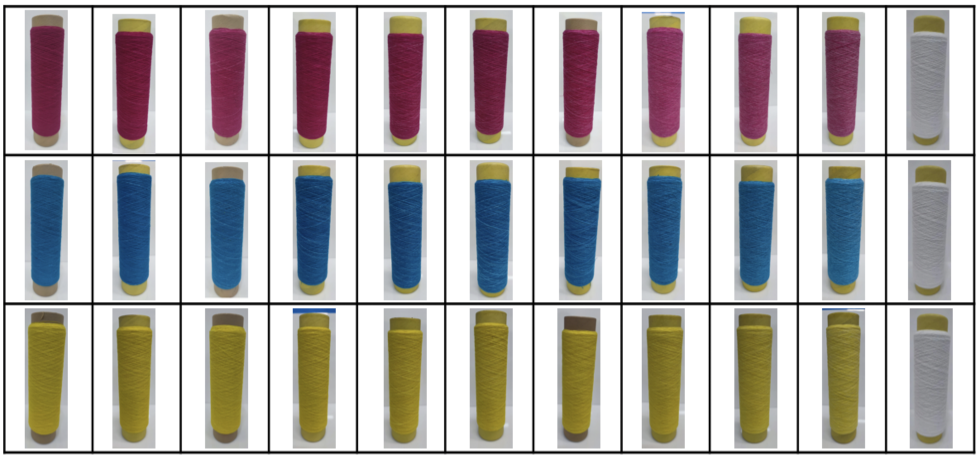

Figure 13. The third type of blended yarn.

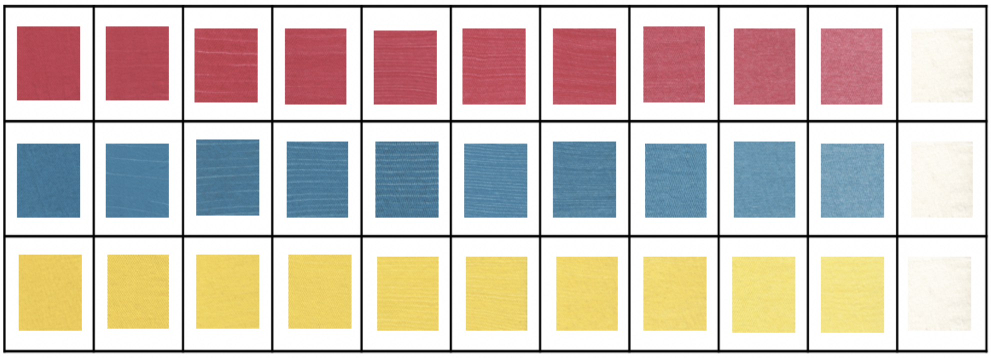

Figure 14. The third type of blended yarn knitted fabric.

Table 9. HSL value of blended yarn.

No.	H	S	L	No.	H	S	L	No.	H	S	L
$C_{1,1}$	337.87	74.48	35.22	$C_{3,1}$	337.99	70.64	36.64	$C_{7,1}$	338.62	65.11	38.54
$C_{1,2}$	331.08	50.1	31.27	$C_{3,2}$	330.14	44.81	33.49	$C_{7,2}$	332.35	41.55	37.03
$C_{1,3}$	325.31	41.85	29.78	$C_{3,3}$	318.56	31.74	31.49	$C_{7,3}$	325.19	31.7	35.11
$C_{1,4}$	313.37	28.73	29.99	$C_{3,4}$	309.14	25.65	31.18	$C_{7,4}$	311.35	22.82	34.22
$C_{1,5}$	283.87	21.9	30.17	$C_{3,5}$	289.91	22.79	30.45	$C_{7,5}$	281.97	17.43	35.08
$C_{1,6}$	263.2	20.41	31.11	$C_{3,6}$	266.21	19.69	31.97	$C_{7,6}$	254.25	16.02	36.93
$C_{1,7}$	227.15	23.85	31.43	$C_{3,7}$	242.04	17.97	35.22	$C_{7,7}$	238.85	15.32	38.52
$C_{1,8}$	213.78	32.96	32.41	$C_{3,8}$	219.74	27.03	34.69	$C_{7,8}$	210.55	30.71	34.96
$C_{1,9}$	198.15	63.51	29.45	$C_{3,9}$	201.64	54.76	28.61	$C_{7,9}$	196.74	54.59	32.83
$C_{1,10}$	192.76	100	24.8	$C_{3,10}$	192.6	96.17	26.64	$C_{7,10}$	194.12	69.59	31.16
$C_{1,11}$	190.4	100	26.92	$C_{3,11}$	189.83	100	28.35	$C_{7,11}$	189.04	100	29.12
$C_{1,12}$	184.6	100	24.13	$C_{3,12}$	188.41	100	27.13	$C_{7,12}$	184.75	100	27.2
$C_{1,13}$	175.26	100	23.17	$C_{3,13}$	175.07	100	23.46	$C_{7,13}$	177.05	88.26	26.18

$C_{1,14}$	162.71	59.99	29.66	$C_{3,14}$	164.85	64.53	29.15	$C_{7,14}$	170.72	55.31	32.83
$C_{1,15}$	154.17	46.32	31.61	$C_{3,15}$	151.96	34.77	34.61	$C_{7,15}$	155.3	31.19	40.76
$C_{1,16}$	121.95	27.8	40.02	$C_{3,16}$	140.81	35.75	37.19	$C_{7,16}$	127.33	25.12	42.59
$C_{1,17}$	120.21	27.04	40.13	$C_{3,17}$	116.6	28.13	39.74	$C_{7,17}$	96.97	29.92	42.08
$C_{1,18}$	73.25	51.19	37.48	$C_{3,18}$	93.22	33.68	40.07	$C_{7,18}$	87	33.41	42.82
$C_{1,19}$	67.42	52.47	38.48	$C_{3,19}$	64.18	56.25	38.45	$C_{7,19}$	65.45	45.42	42.63
$C_{1,20}$	63.3	60.62	37.99	$C_{3,20}$	51.87	100	37.49	$C_{7,20}$	51.26	61.9	45.93
$C_{1,21}$	45.85	100	45.63	$C_{3,21}$	46.51	100	45.89	$C_{7,21}$	46.58	93.61	47.83
$C_{1,22}$	31.88	71.93	45.19	$C_{3,22}$	34.67	76.39	44.74	$C_{7,22}$	35.17	62.32	50.06
$C_{1,23}$	24.43	63.58	44.58	$C_{3,23}$	27.54	66.57	45.03	$C_{7,23}$	24.68	54.65	47.93
$C_{1,24}$	17.44	56.24	45.91	$C_{3,24}$	15.06	49.63	47.44	$C_{7,24}$	19.54	48.96	49.41
$C_{1,25}$	16.05	56.68	44.58	$C_{3,25}$	9.41	48.38	46.31	$C_{7,25}$	10.81	45.62	48.63
$C_{1,26}$	6.59	49.9	45.19	$C_{3,26}$	8.96	51.91	44.54	$C_{7,26}$	5.67	42.69	47.56
$C_{1,27}$	0.85	47.68	44.64	$C_{3,27}$	0.39	46.53	45.82	$C_{7,27}$	356.75	41.19	47.86
$C_{1,28}$	0.07	48.78	44.21	$C_{3,28}$	359.91	45.11	46.17	$C_{7,28}$	350.9	46.11	44.94
$C_{1,29}$	350.08	57.42	41.09	$C_{3,29}$	349.34	57.54	40.65	$C_{7,29}$	350.31	44.74	46.05
$C_{1,30}$	343.87	64.9	38.58	$C_{3,30}$	345.58	60.03	39.85	$C_{7,30}$	345.17	48.77	44.31

Table 10. HSL value of blended yarn.

No.	H	S	L	No.	H	S	L	No.	H	S	L
$C_{1,5}$	283.87	21.9	30.17	$C_{1,15}$	154.17	46.32	31.61	$C_{1,25}$	11.05	56.68	44.58
$C_{2,5}$	285.71	20.7	30.32	$C_{2,15}$	152.14	30.31	31.94	$C_{2,25}$	11.78	54	44.3
$C_{3,5}$	289.91	22.79	30.45	$C_{3,15}$	151.96	34.77	34.61	$C_{3,25}$	10.41	48.38	46.31
$C_{4,5}$	286.69	22.03	30.59	$C_{4,15}$	155.4	44.01	34.68	$C_{4,25}$	10.44	48.13	46.54
$C_{5,5}$	288.58	20.32	30.71	$C_{5,15}$	153.98	34.06	38.15	$C_{5,25}$	10.52	46.46	47.97
$C_{6,5}$	289.39	19.05	32.3	$C_{6,15}$	151.58	35.05	38.37	$C_{6,25}$	10.95	45.05	47.99
$C_{7,5}$	281.97	17.43	35.08	$C_{7,15}$	155.3	31.19	40.76	$C_{7,25}$	10.81	45.62	48.63
$C_{8,5}$	284.79	16.21	36.15	$C_{8,15}$	154.79	33.1	40.52	$C_{8,25}$	10.44	43.38	50.74
$C_{9,5}$	283.42	13.02	40.77	$C_{9,15}$	154.15	28.25	43.81	$C_{9,25}$	11	43.34	55.45
$C_{10,5}$	287.25	10.05	49.91	$C_{10,15}$	151.9	20.16	52.25	$C_{10,25}$	10.82	41.86	57.64

Table 11. HSL value of blended yarn.

No.	H	S	L	No.	H	S	L	No.	H	S	L
$C_{1,1}$	337.87	74.48	35.22	$C_{1,11}$	190.4	100	26.92	$C_{1,21}$	45.85	100	45.63
$C_{2,1}$	337.87	72.51	36.72	$C_{2,11}$	190.36	100	27.37	$C_{2,21}$	46.02	100	45.86
$C_{3,1}$	337.99	70.64	36.64	$C_{3,11}$	189.83	100	28.35	$C_{3,21}$	46.51	100	45.89
$C_{4,1}$	338.73	63.71	39.11	$C_{4,11}$	190.1	100	28.56	$C_{4,21}$	46.51	100	45.33
$C_{5,1}$	339.07	60.15	39.94	$C_{5,11}$	189.78	100	28.36	$C_{5,21}$	46.75	100	45.92
$C_{6,1}$	339.28	57.43	41.05	$C_{6,11}$	189.25	100	28.36	$C_{6,21}$	46.68	100	45.85
$C_{7,1}$	338.62	65.11	38.54	$C_{7,11}$	189.04	100	29.12	$C_{7,21}$	46.58	93.61	47.83
$C_{8,1}$	340.16	47.34	45.46	$C_{8,11}$	188.78	100	29.41	$C_{8,21}$	44.95	82.35	53.03
$C_{9,1}$	340.43	40.77	48.67	$C_{9,11}$	188.64	81.93	33.74	$C_{9,21}$	44.49	81.85	59.27
$C_{10,1}$	340.68	39.53	53.18	$C_{10,11}$	190.33	48.47	44.31	$C_{10,21}$	44.89	83.12	60.42

Conclusion

CNC rotor spinning is characterized by asynchronous feeding of multiple slivers (multiple channels), which can control the blending ratio, linear density, and twist of the spun yarn online. As a new process method for spinning full-color gamut color yarn, the color yarn based on three-channel NC rotor spinning has the characteristics of intelligence, flexibility, and digitalization compared with traditional color spinning. It can adjust the timing change of spinning forming color online based on an intelligent algorithm, realize the accurate change of hue, lightness, and chromaticity of mixed color based on digital color matching, and realize full-color gamut color matching based on the optimization of color matching mode; it has the advantages of the short color matching process, high color matching efficiency, and low labour cost. This paper explores the mechanism and method of realizing full-color gamut blending spinning by combining the full-color gamut blending model with the mechanism of a three-channel CNC rotor spinning machine to control the proportion of multi-color fibers. In order to construct a grid color mixing model based on four primary color fibers, three groups of dyes with a color difference of about 120 °C were selected as color three primary colors and gray fibers as four primary color fibers.

Through the grid color mixing model of four primary color fibers, a digital color mixing model that can control hue, brightness, and chromaticity within the full-color gamut was constructed; in order to clarify the color mixing mechanism of a three-channel rotor spinning full-color gamut based on the three-channel rotor CNC spinning platform, a color mixing spinning mechanism of coordinated control of multi-channel draft ratio, color mixing ratio of primary color fiber and color of formed yarn was constructed; in order to verify the mechanism of full-color gamut color spinning, 156 grid point color mixing samples were selected in the grid color mixing model, and the blended yarn and its knitted fabric were spun according to three series of an isochromatic and different hue, isochromatic and different lightness, isochromatic, and different chromaticity and the color, evenness, strength, and hairiness of the blended yarn were tested and analyzed. The results show that the color change of the blended yarn and its fabric spun based on the full-color gamut grid color blending model is consistent with that of the blended yarn; it is feasible to spin full-color gamut blended yarn based on the control of multi-channel feeding speed ratio and the mixing ratio of primary color fibers.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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