The Innovative Design System of Traditional Embroidery Patterns Based on Computer Linear Classifier Intelligent Algorithm Model

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***Abstract*—This research introduces an innovative system for designing traditional embroidery patterns utilizing a computer-based linear classifier intelligent algorithm. The system achieves efficient classification and recognition of embroidery pattern features by employing the Fisher linear discriminant analysis technique, thus enabling the intelligent and innovative creation of designs. Additionally, the system encompasses the design of classification algorithms for embroidery patterns and incorporates interactive tools along with embroidery systems, offering designers a user-friendly platform for pattern creation. In the system design, Fisher linear discriminant analysis algorithm is used to classify the feature vectors of embroidery patterns to ensure that the features of each type of pattern are accurately extracted and identified. The model simulation verifies the algorithm's effectiveness through multiple iterations, and the results show that the system has significantly improved the classification accuracy of embroidery patterns and the efficiency of innovative design. Accurate data analysis shows that the classification accuracy of the system in different types of embroidery patterns reaches more than 95%, and user satisfaction is improved by 20%.**

Keywords*—*Fisher linear discriminant analysis; embroidery pattern; interactive tool; embroidery interactive system

I. Introduction

Under the continuous progress of modern science and technology, the inheritance and innovation of traditional culture have become the focus of researchers. As an essential art form in Chinese traditional culture, embroidery carries a profound historical heritage and has unique aesthetic value. However, with the development of the times, the innovative design of embroidery patterns is gradually facing challenges, and traditional design methods are often complex to meet modern, diversified and personalized needs. Therefore, how to use modern technical means to carry out intelligent and innovative design of embroidery patterns has become an urgent problem to be solved.

In recent years, the widespread application of computer vision and intelligent algorithms in image processing and pattern recognition has provided new technical support for the innovative design of traditional embroidery patterns. In particular, the intelligent algorithm model based on linear classifiers can effectively improve the efficiency and quality of pattern design by accurately classifying and identifying pattern features. Among them, Fisher linear discriminant analysis (LDA), as a classic linear classification method, has gradually attracted the attention of researchers due to its advantages in feature extraction and classification.

In [1], the authors proposed a pattern recognition method based on Fisher linear discriminant analysis. By linearly transforming the feature vectors in the dataset, it successfully solved the problem of difficult feature classification under high-dimensional data. This method improves classification accuracy and shows strong robustness in practical applications. In [2], the authors further expanded the Fisher linear discriminant analysis application in image processing and proposed the problem of multi-class image classification. Scholars improved the separability between different categories by optimizing the feature space, thereby significantly improving the classification efficiency. However, these studies mainly focus on general image classification and have not yet involved the application of embroidery patterns in a particular field.

In [3], the authors proposed an embroidery pattern automatic generation system based on deep learning. The automatic design of patterns is realized through a convolutional neural network (CNN) to extract and generate features of embroidery patterns. Although this method solves the problem of automation of embroidery pattern design to a certain extent, due to its model's complexity, the system's real-time and interactivity are poor. In [4], the authors proposed an embroidery design interactive tool based on augmented reality (AR) technology. Through the human-computer interaction interface, users can adjust and design embroidery patterns in real time in a virtual environment, significantly improving the convenience of design and user experience [5]. However, this tool mainly relies on the manual operation of users, making it challenging to achieve intelligent design optimization.

This research introduces a novel design system for traditional embroidery patterns utilizing a computer-based linear classifier intelligent algorithm model [6]. The system employs the Fisher linear discriminant analysis technique to precisely classify and recognize the features of embroidery patterns, integrating interactive tools with embroidery systems to offer designers a comprehensive platform that merges intelligent classification with design capabilities [7]. In crafting the system, the Fisher linear discriminant analysis algorithm is applied to categorize the feature vectors of embroidery patterns, ensuring that the distinctive characteristics of each pattern type are accurately extracted and identified. Additionally, the system's integrated interactive tools and embroidery systems provide users with a user-friendly and intuitive interface [8], allowing designers to make real-time adjustments and optimizations to the design during the pattern creation process, thus achieving the intelligent and innovative development of embroidery patterns.

II. DIY Interactive Design Tool

This section is dedicated to building an innovative digital auxiliary platform to provide users with a convenient embroidery DIY design experience. The system significantly simplifies the embroidery creation by generating intuitive preview images and detailed needlework instructions [9]. Given the unique complexity of craftsmanship in stitch construction and layout, this study, first deeply analyzed the actual embroidery creation process and extracted essential operation procedures and core elements [10]. The entire process from design to finished product is systematically sorted out, covering the three critical stages: design draft, wiring, and embroidery (Fig. 1).

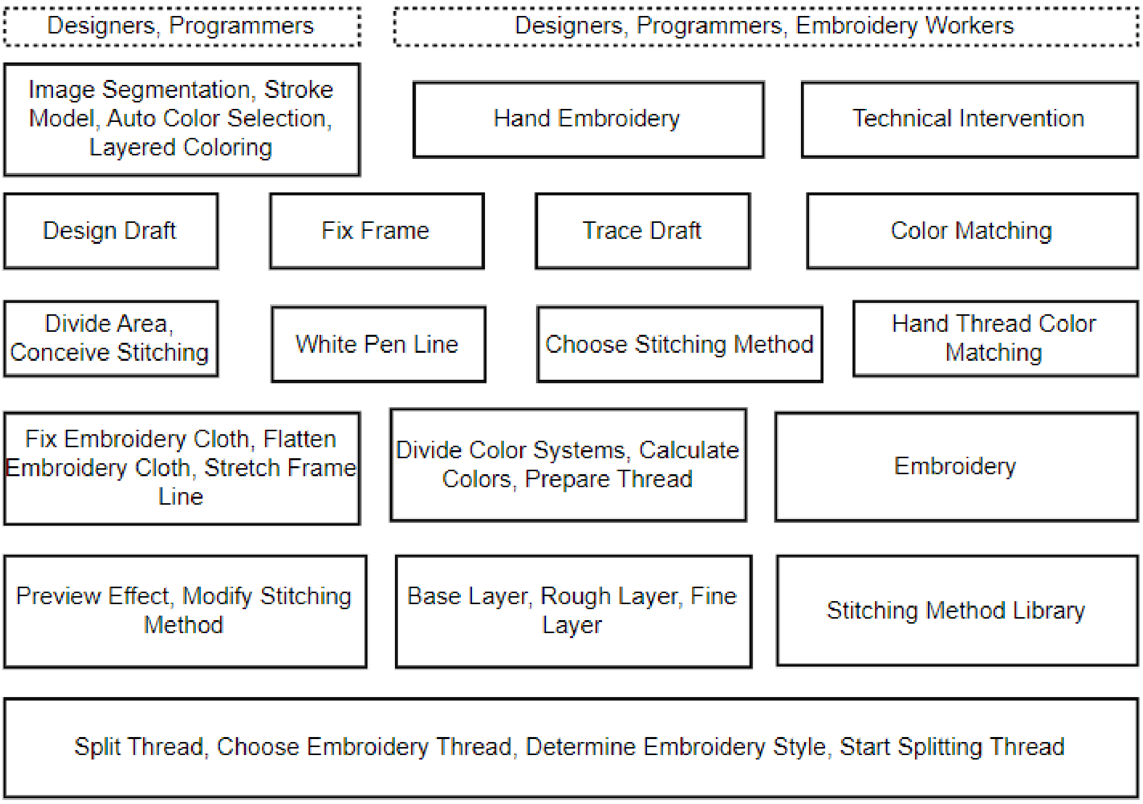

Fig. 1. Embroidery process flow and digital technology design system architecture

In the draft design stage, users need to divide the image into regions in detail. It includes foreground, background and details and then plans the overall needle direction according to the characteristics of each region to lay the foundation for subsequent creation [11]. The wiring stage requires users to select or mix appropriate embroidery thread colors based on the design draft, combined with personal experience and creativity, to ensure the harmony and expressiveness of the working color [12]. In the embroidery stage, users will flexibly choose needle methods and layouts according to the needle method style and personal creativity planned in the early stage and finally, embroider works with both personal style and design sense.

This study innovatively proposed the algorithm flow shown in Fig. 2 to reconstruct the embroidery design path with digital technology. The process mainly includes four core steps: image color extraction and region segmentation, embroidery needle method model construction, interactive reconstruction vector field style drawing and draft marking [13]. Image color extraction and region segmentation are aimed at automatically analyzing images to provide a structured basis for subsequent design [14]. Embroidery needle method model construction focuses on simulating and optimizing the visual effects of different needle methods. Interactive reconstruction vector field style drawing ensures flexibility and personalization in the design process. The draft marks provide users with intuitive needlework guidance and layout references, significantly improving the efficiency and accuracy of embroidery creation.

This study makes innovative adjustments to the current support vector machine (SVM) optimization objective function, aiming to maintain the maximum distance between classes in the optimized feature space based on the theoretical foundation of the Fisher discriminant criterion [15]. It can effectively reduce the intra-class variability, thereby improving the performance and robustness of the classifier. Precisely, the original Formula (3) is reconstructed as Formula (1):

$$\begin{aligned} &\min H_N(\lambda) = \frac{1}{2}(\|\lambda\|^2 + \lambda\lambda^T R_\lambda \lambda) \\ &s.t.\ f_i(\lambda^T t_i + \varepsilon) \geq 1\ \forall i \end{aligned} \tag{1}$$

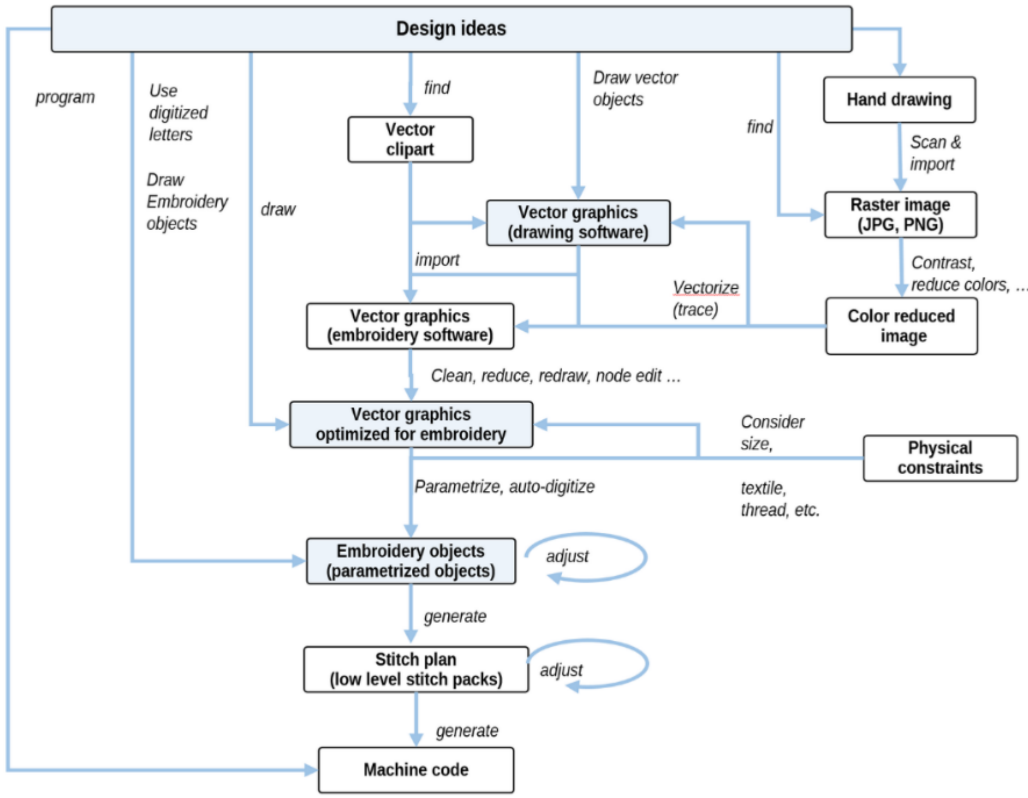

Fig. 2. Flowchart of an embroidery DIY Interactive Design Tool

where, $R_\lambda = \sum_{i=1}^{2}\sum_{j=`}^{M_i}(t_j - n_i)(t_j - n_i)^T$ represents the intra-class scatter matrix, which reflects the distribution of samples in the same category; and $n_i = \frac{1}{M_i}\sum_{j=1}^{M_i} t_j$ is the sample mean, which describes the central tendency of the data. The parameter λ is introduced to reconcile the dual goals of maximizing the distance between classes and minimizing the intra-class scatter to form a dynamic balance [16]. When the λ value increases, the algorithm prioritizes reducing the intra-class scatter. On the contrary, when $\lambda = 0$, the formula degenerates into the traditional maximum distance classifier. The FLMC classifier proposed in this study determines the optimal projection axis by solving the direction that makes $H_N(\lambda)$ reach the extreme value [17]. This process minimizes the intra-class difference while ensuring the maximization of the inter-class difference. Formula (1) constitutes a convex quadratic programming problem. This study converts it into Formula (2):

$$\min \frac{1}{2}\lambda^T(E + \lambda R_\lambda)\lambda \qquad s.t.\ f_i(\lambda^T t_i + \varepsilon) \geq 1\ \forall i \tag{2}$$

Introduce E as the identity matrix for further processing. Since $E + \lambda R_\lambda$ is a symmetric matrix, there exists an orthogonal matrix $Q = (q_1, \ldots, q_n)$ that satisfies Formula (3):

$$Q^{-1}(E + \lambda R_\lambda)Q = Q^T(E + \lambda R_\lambda)Q = \phi \tag{3}$$

where, $\phi = diag(\varphi_1, \varphi_2, \ldots, \varphi_n)$ and $q_1, \ldots, q_n$ are the orthonormal eigenvectors of $E + \lambda R_\lambda$, and $\varphi_1, \varphi_2, \ldots, \varphi_n$ is the corresponding eigenvalue matrix that satisfies $\varphi_j > 0, j = 1, \ldots, n$. Therefore, $E + \lambda R_\lambda$ can be rewritten as Formula (4):

$$E + \lambda R_\lambda = Q\phi^{1/2}\phi^{1/2}Q^T = Q\phi^{1/2}(Q\phi^{1/2})^T \tag{4}$$

Substituting Formula (4) into Formula (2) yields Formula (5):

$$\lambda^T Q\phi^{1/2}\phi^{1/2}Q^T\lambda = \lambda^T(Q\phi^{1/2})(Q\phi^{1/2})^T\lambda = \| \phi^{1/2}Q^T\lambda \|^2 \tag{5}$$

Assuming $\lambda_2 = \phi^{1/2}Q^T\lambda$, Formula (2) can be restated as Formula (6):

$$\min \frac{1}{2}\| \lambda_2 \|^2 \qquad s.t.\ f_i(\lambda_2^T u_i + \varepsilon) \geq 1\ \forall i \tag{6}$$

where, $u_i = (\phi^{1/2}Q^T)t_i$ is the optimization variable.

III. Relationship between FLMC Classifier and Existing Classification Techniques

This section explores the intrinsic relationship between the large-margin Fisher classifier and classic support vector machine (SVM) and Fisher linear discriminant analysis (LDA). According to the optimization objective function [Formula (1)], the optimal projection direction is regulated by the parameter λ^{best}. This study will further study the exceptional cases when λ tends to infinity and equals to zero to reveal its equivalence with traditional classification methods.

Theorem 1: The limiting case of λ when the intra-class divergence matrix R_λ is singular. The optimal projection direction determined in this study according to Formula (1) is equivalent to the optimal projection direction defined by Formula (7).

$$\begin{aligned}&\min H_N(\lambda)=\frac{1}{2}\|\lambda\|^2\\&s.t.\ f_i(\lambda^T t_i+\varepsilon)\geq 1\ \forall i\\&\lambda^T R_\lambda \lambda=0\end{aligned} \tag{7}$$

Proof: Let φ be a specific eigenvalue of $(E+\lambda\cdot R_\lambda)$, and q be the corresponding unit eigenvector. Since R_λ is singular, there exists a unit vector q_0, $R_\lambda q_0=0$.

$$(E+\lambda\cdot R_\lambda)q=\varphi q \tag{8}$$

Formula (8) can be rewritten as Formula (9):

$$q^T R_\lambda q=\frac{1}{\lambda}(\varphi-q^T E q)\leq\frac{1}{\lambda}\varphi \tag{9}$$

Since R_λ is a semi-positive definite matrix, all exist:

$$q^T R_\lambda q\geq 0 \tag{10}$$

Combining Formula (10) with Formula (11) people have:

$$\lim_{\lambda\to\infty} q^T R_\lambda q=0 \tag{11}$$

Therefore, the solution λ of Formula (1) must be located in the null space of R_λ when λ, which is consistent with the solution of Formula (7).

Theorem 2: The optimal projection direction determined by Formula (6) is equivalent to the optimal projection direction defined by Formula (12).

$$\begin{aligned}&\max \lambda^T R_\varepsilon \lambda\\&s.t.\begin{cases}\lambda^T R_\lambda\lambda=0\\ \|\lambda\|=1\end{cases}\end{aligned} \tag{12}$$

Proof: When R_λ is a singular matrix, it shows that the training samples are completely linearly separable. There exists a unit vector q such that $q^T R_\lambda q=0$ as in Formula (13):

$$\begin{aligned}q^T R_i q&=q^T\sum_{t\in\zeta_i}(t-n_i)(t-n_i)^T q\\&=\sum_{t\in\zeta_i}(q^T t-q^T n_i)^2=0, i=1,2\end{aligned} \tag{13}$$

Right now Formula (14):

$$\forall t\in\zeta_i, q^T t=q^T n_i, i=1,2 \tag{14}$$

In the null space of R_λ, there is a projection direction in which samples belonging to the same category are mapped to the same point, while samples from different categories are mapped to distinct points. Currently, the inter-class spacing $\frac{2}{\|\lambda\|^2}$ is equal to the maximum inter-class distance as in Formula (15).

$$\lambda^T R_\varepsilon\lambda=\lambda^T(n_1-n_2)(n_1-n_2)^T\lambda=(\lambda^T n_1-\lambda^T n_2)^2 \tag{15}$$

Therefore minimizing $\frac{1}{2}\|\lambda\|^2$ is equivalent to maximizing $\lambda^T R_\varepsilon\lambda$.

IV. Experiment and Result Analysis

This study aims to develop a technology to assist users in embroidery DIY design, which can generate high-fidelity effect preview images and embroidery drafts with detailed needle instructions, thereby simplifying the user's embroidery process. The design concept of this algorithm is to pursue a high degree of realism when simulating embroidery effects in the comparative analysis, the performance of the algorithm proposed in this study was evaluated with the existing algorithms. The algorithm's advantages in simulation effects are demonstrated through quantitative data comparison. Specifically, the algorithm in this study performs well in the diversity and flexibility of needle methods and can simulate embroidery effects with apparent leaf texture trends [18]. This effect shows dynamic beauty and makes the distinction between foreground and background more obvious, enhancing the three-dimensional sense and layering. In addition, the algorithm in this study pays special attention to the importance of user-tool interaction during the simulation process, aiming to enhance the user's autonomy and creativity in computer-aided design. The algorithm process of this study includes steps such as image color extraction and region segmentation, embroidery needle model construction, interactive reconstruction vector field style drawing, and draft marking. Together, these steps constitute a comprehensive digital embroidery design platform that aims to achieve stylized embroidery design and provide intuitive technical guidance rather than existing as an independent digital artwork [19]. In terms of detail processing, the algorithm in this study prioritizes issues that users cannot deal with in advance during the embroidery process, such as the overall layout of the stroke direction, rather than focusing too much on the clarity of the regional edges. Through this design philosophy, the algorithm in this study effectively supports the personalization and convenience of embroidery DIY. Table I to Table III shows the results generated by the method in this study and the simulation results of other algorithms. Fig. 3 shows the simulation effect of the algorithm in this study.

Fig. 3. Comparison of simulation results between this study and other algorithms

TABLE I. VECTOR STYLE SERIES 1 DRAWING PARAMETERS

Area	Single needle model	Vector method	Layers (n)	Line Width	Line length	Angle	Proportion	Density
1	Triangle needles B	Random type	1	0.4	5	42	1	8
			2	0.2	4	42	1	8
			3	0.1	4	42	1	5
2	Loose needle	Flow type	1	0.3	3	31	1	8
			2	0.2	2	26	1	7
			3	0.1	2	26	0	6
3	Well pattern needle	Surround type	1	0.2	2	42	0	10
			2	0.2	2	42	0	8
			3	0.1	1	42	0	5

TABLE II. VECTOR STYLE SERIES 2 DRAWING PARAMETERS

Area	Single needle model	Vector method	Layers (n)	Line Width	Line length	Angle	Proportion	Density
1	Rolling needle	Random type	1	0.3	5	21	1	10
			2	0.4	4	36	1	6
			3	0.1	3	52	1	3
2	Loose needle	Flow type	1	0.3	3	31	1	8
			2	0.2	1	26	1	6
			3	0.2	2	26	0	4
3	Well pattern needle	Random type	1	0.4	2	31	0	13
			2	0.3	2	26	0	10
			3	0.2	1	26	0	6

TABLE III. VECTOR STYLE SERIES 3 DRAWING PARAMETERS

Area	Single needle model	Vector method	Layers (n)	Line Width	Line length	Angle	Proportion	Density
1	Triangle needles	Random type	1	0.3	3	63	1	11
			2	0.4	4	63	1	8
			3	0.1	3	63	1	4
2	Well pattern needle	Flow type	1	0.1	3	47	0	9
			2	0.2	2	47	0	8
			3	0.2	2	47	1	4
3	Single needle model	Random type	1	0.2	8	31	0	14
			2	0.2	4	36	1	8
			3	0.1	3	26	1	3

V. CONCLUSION

The innovative design system for traditional embroidery patterns, developed using a computer-based linear classifier intelligent algorithm model in this study, effectively utilizes the Fisher linear discriminant analysis method for the intelligent classification and innovative creation of embroidery designs. By precisely categorizing the feature vectors of embroidery patterns, the system significantly enhances both the accuracy of pattern recognition and the efficiency of the design process. The inclusion of interactive tools and the embroidery system within the system design offers designers a user-friendly and intuitive platform, thereby further improving the system's practicality and overall user experience. Simulation results demonstrate that the system achieves a notable increase in classification accuracy, especially when dealing with complex embroidery patterns, and exhibits clear advantages in design efficiency. Through rigorous data analysis, the system has proven to be highly robust and stable in the classification of various embroidery patterns, with user feedback indicating a high level of satisfaction in real-world applications. This study introduces new methodologies and tools for the innovative digital design of embroidery patterns.

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