A Computer Vision-Based System for Automatic Detection of Misarranged Color Warp Yarns in Yarn-Dyed Fabric. Part III: Yarn Layout Proofing

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Abstract This series of studies aims to develop a computer vision-based system for automatic detection of misarranged color warp yarns. This paper proposes a yarn layout proofing strategy, integrating with the warp yarn segmentation and fabric image stitching methods proposed in Part I (Zhang, Wang, Pan, Zhou, & Gao, 2018) and warp region segmentation method proposed in Part II (Zhang, Wang, & Pan, 2019), to achieve system automation. In the previous papers, the frame images of fabric stripe are captured by a designed image acquisition platform, the warp yarns and regions of frame images are segmented successively, and the fabric frame images are stitched, the comprehensive information of color warps are saved as two vector, including the widths of warp regions and the layout of color yarns. In this paper, through analyzing different forms of misarranged color warps, a standard yarn layout-based proofing strategy is developed to detect the misarranged color warp yarns. Experiment results demonstrate that the proposed method is proposing for the layout proofing of color warp yarns in multicolor yarn-dyed fabrics of color stripes and color checks with satisfactory accuracy and good robustness.

Keywords: misarranged color yarns, layout of color yarns; yarn-dyed fabric; yarn layout proofing.

The layout of color yarns is the color information of the warp and weft yarns in a repeat, which is significant structure parameter for yarn-dyed fabrics. The misarranged color warps break the standard layout of color warp yarns so that they make a great negative influence on product quality and selling price. However, the traditional work to detect the misarranged color warps is greatly laborious and time-consuming during the production process. To increase the efficiency of yarn layout detection and improve the quality of yarn-dyed fabrics, this series of studies propose a computer vision-based system for automatic detection of the misarranged color warps of yarn-dyed fabric.

Part I of the series of the studies develops an image acquisition and processing platform to capture a series of continuous images of a real yarn-dyed fabric along the direction of weft yarns. A fragment of the real color stripe with one misarranged color warp is shown in Figure 1, which are made from white and blue warps and white weft (the size of the real color stripe is around 160cm×5cm). The detected layout of warp yarns of the color stripe is shown in Figure 1. Part I of the series of the studies demonstrates the sub-image projection-based method to segment warp yarns and yarn-template matching method to stitch fabric images with excellent results (Zhang, et al., 2018). The warp yarns of fabric image in Figure 1 are segmented automatically, shown as the red lines in Figure 1. Furthermore, Part I of the series of the studies propose a yarn-template matching method to stitch two frame images based on their warp segmentation result. Two neighbor frame images are stitched, and the matching warp center lines are founded as the green lines shown in Figure 1.

Part II of the series of the studies develops proposed an HSI color histogram-based correlation coefficient analysis method to segment the warp regions (Zhang, et al., 2019). The fabric images of frame 1 and 2 are segmented into 10 and 8 blocks by the blue lines respectively. The segmentation results of warp yarns and regions are converted into the corresponding vectors, as shown in the middle and bottom of Figure 1. The Vector ① of the warp regional segmentation indicates the width of each warp regions, as illustrated in the bottom of Figure 1. The number in each color blocks is the corresponding warp regional width. The Vector ② of the inspected yarn layout indicates the number of warp yarns in each warp regions, as illustrated in the bottom of Figure 1. Based on the Vector ① and ② and the provided standard color yarn layout, the misarranged color yarn can be detected indicated by the red arrow by the proposed yarn layout proofing method.

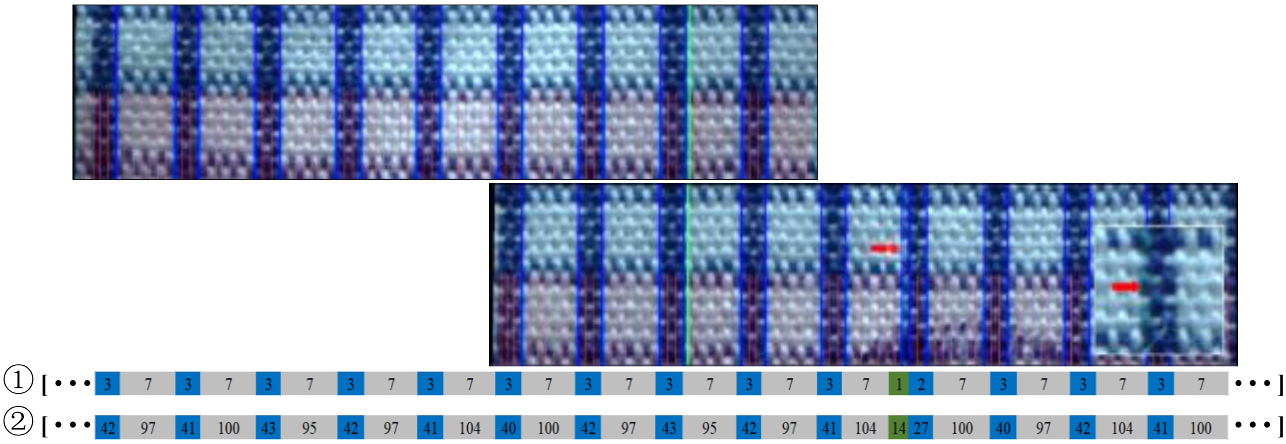


Figure 1. Stitched two frame images of the real color stripe with one misarranged color warp and their warp vectors.

This paper aims to realize the yarn layout proofing by integrating previous study of the warp yarn segmentation and fabric image stitching methods proposed in Part I and warp region segmentation method proposed in Part II in order to achieve system automation. In the previous papers, the frame images of fabric stripe are captured by using a designed image acquisition platform, the warp yarns and regions of frame images are segmented successively and the fabric frame images are stitched, the comprehensive information of color warps are saved as two vector, including the widths of warp regions and the layout of color yarns. In this paper, by analyzing different forms of misarranged color warps, a standard yarn layout-based proofing strategy is developed to detect the misarranged color warp yarns.

This paper is organized as follows. Section2 outlines the framework and gives an overview of the process chain. Section 3 guides the readers through experimental details of a multiple color fabric example, especially describes the warp yarn segmentation, warp region segmentation, fabric image stitching methods and yarn layout proofing strategy. Section 3 presents the inspection results for yarn layout proofing, and discusses the framework with regard to strengths and weaknesses. We conclude the proposed method and introduce the future work in Section 5.

2. Process chain overview

The main objective of these series of studies is to find the misarranged warp yarn in color fabric samples. To achieve the objectives, a series processing procedure are proposed in different parts. As given in Figure 2, the overall process chain includes image acquisition, yarn and warp region segmentation, region merging and stitching, and yarn layout proofing. The further steps are aim to extract the region data in the input yarn-dyed fabric strip sample, which include the pixel with and yarn number of every color region. Then the region data are converted into two region vectors and processed by a yarn layout proofing method, which can locate the regions that contain any misarranged yarns.

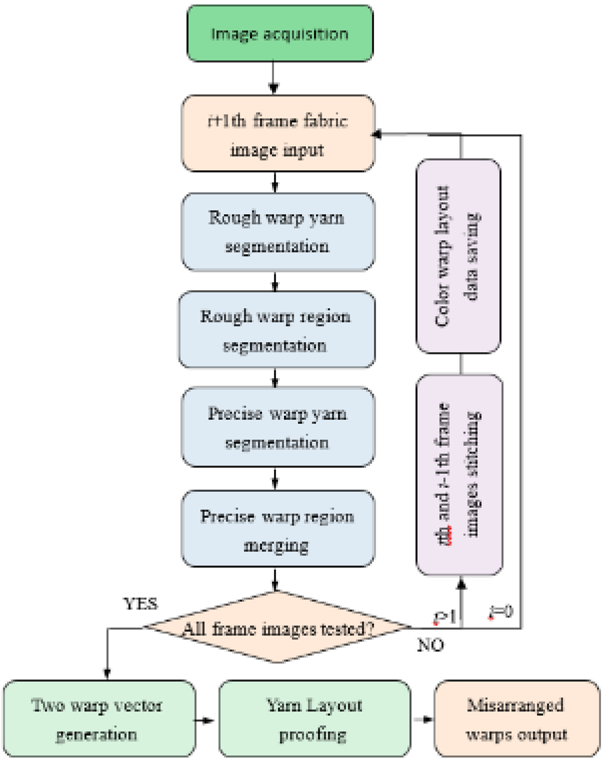


Figure 2. Block diagram of the proposed framework.

3 Machine vision algorithms

In this section, an example of multiple color fabric is adopted for describing the warp yarn segmentation and fabric image stitching methods. A fabric strip with the size around 160 cm × 5 cm is placed on the driving belt, and 175 sequential frame images are captured by the image acquisition platform. Figure 3 shows the one frame image of the multiple-color fabric example. The fabric example is made of two different color warps (blue and white) and two different color wefts (blue and white). The standard layout of color warps is: 3 blue and 7 white warp yarns successively.

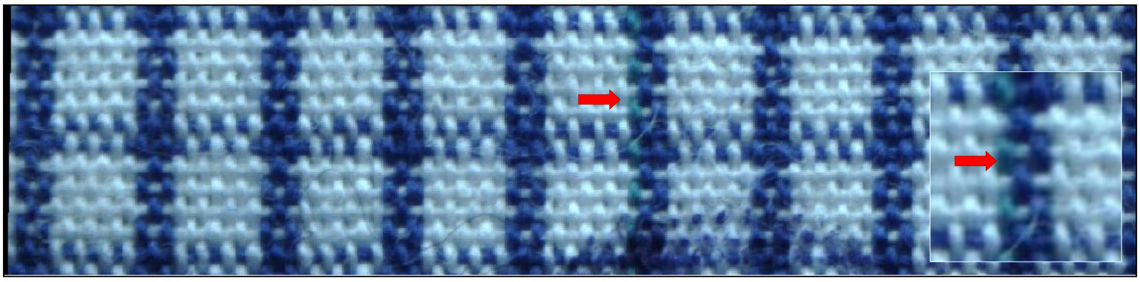


Figure 3. A fragment of the multiple-color fabric example.

3.1 Warp yarn segmentation

To segment the warp yarns precisely, the sub-image projection-based yarn segmentation method (Zhang, Pan, Gao, & Zhu, 2014; Zhang, et al., 2018) is adopted. The fabric image can be divided into a number of sub-images and every sub-image are projected in column. The warp locations are determined by analyzing all projection curve of sub-images synthetically.

The yarn-dyed fabric image is divided into s sub-images whose height and width are $h \times N$, where s=$fix(M/h)$. s is the number of the sub-images. M×N are the size of the fabric image. h is the height of the sub-images. The projection curves of every sub-image are smoothed by locally weighted regression (LOESS) algorithm (Cleveland, 1979, 1981) to eliminate the noise points. The span of LOESS algorithm S_1= d_{warp}×γ_1, where γ_1 is a proportionality constant. The warp segmentation result of the frame image is shown in Figure 5. In Figure 5, the red lines are the segmented warp boundaries.

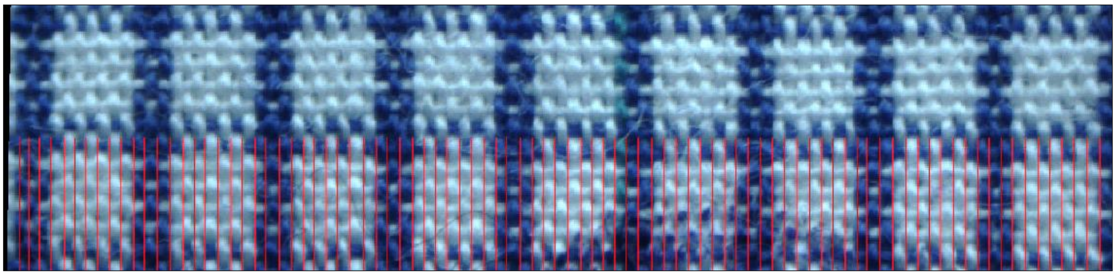


Figure 4. Warp yarn segmentation result.

3.2 Warp region segmentation

Rough warp region segmentation In this section, based on the warp yarn segmentation, the color warp region are segmented roughly by analyzing correlation coefficient curve of HSI color histogram of warp yarns (Zhang, et al., 2019). In yarn-dyed fabric image, if the colors of two neighbor warps are same, their color histogram is nearly same and the corresponding correlation coefficient is lager. Nevertheless, if the colors of two neighbor warps are different, their color histogram is different and the corresponding correlation coefficient is smaller. This warp color features are utilized into segmenting warp regions roughly as following steps. The correlation coefficient curve of HSI color histogram of warp yarns is generated as shown in Figure 5. The rough warp region segmentation result is shown in Figure 6. The fabric warps are divided into 21 color regions.

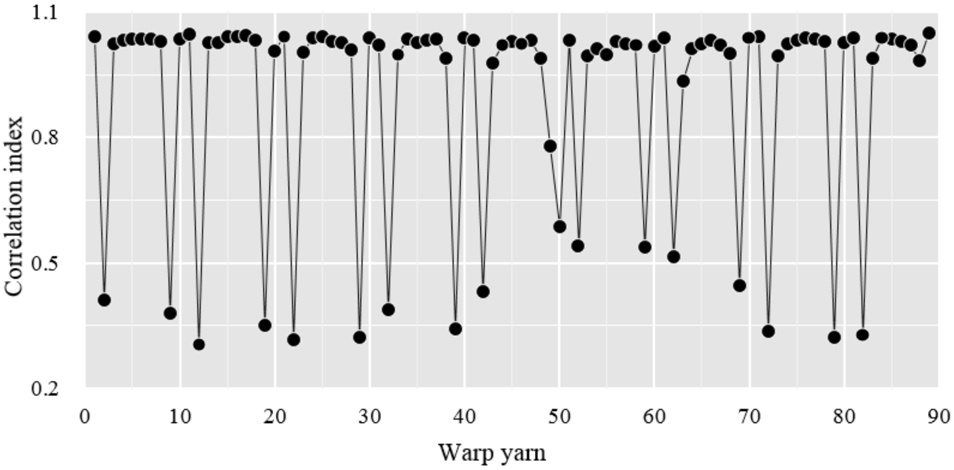


Figure 5. Correlation coefficient curve of HSI color histogram of warp yarns.

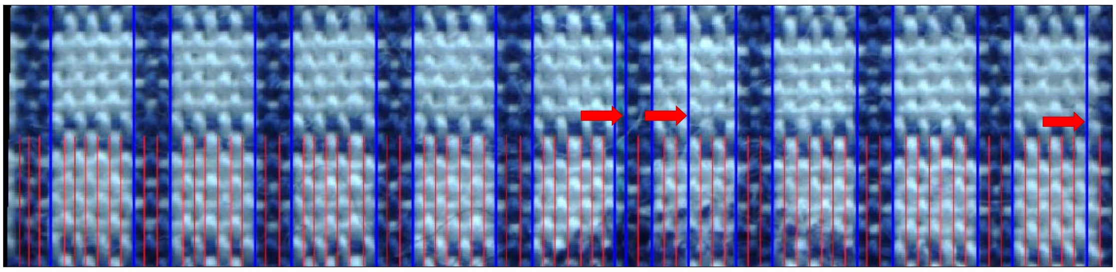
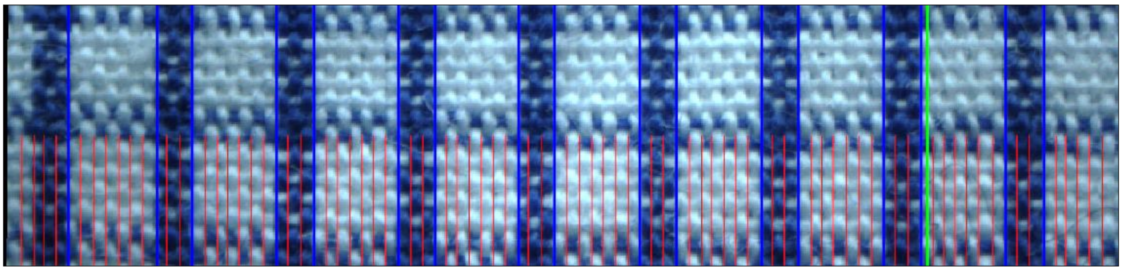


Figure 6. Rough warp region segmentation result.

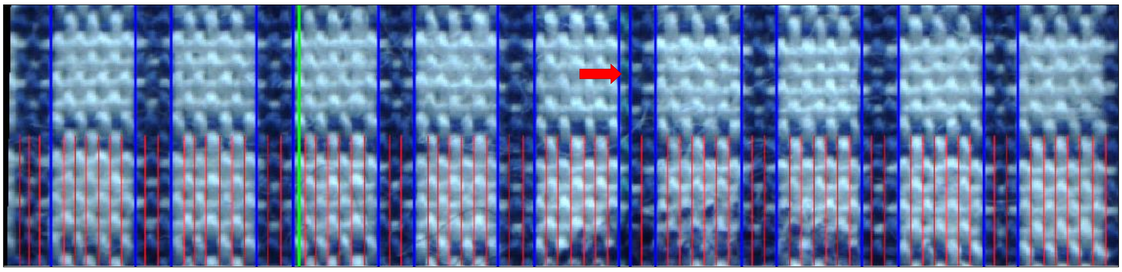
Precise warp region merging To remove the over-segmented warp boundaries, warp regions are merged precisely by calculating the correlation coefficient of HSI color histogram of warp regions. The correlation coefficients between two integrating color histograms of neighbor warp regions are calculated successively. The warp region segmentation result by precisely merging warp regions is shown in the Figure 7(b). In Figure 7(b), the three over-segmented warp boundaries are removed successfully.

3.3 Image stitching method

Two continuous frame images are utilized to present the fabric image stitching method. A yarn-template matching method is adopted to stitch two neighbor frame images (Zhang, et al., 2018). A rectangle region is extracted as a template t from the 3rd frame, whose center locates in the warp center lines, shown as the green line with red square in Figure 7(a).Based on the template extracted from the former frame (Figure 7(a)) of the images, the coincident point in the next frame (Figure 7(b)) is detected using zeros-mean-normalized-cross-correlation (ZNCC) measurement (Schneider, 2013). Based on the correlation map corresponding to the searching scope, the 25th warp has the maximum correlation index, as the green line shown in frame of Figure 7(b), which means that the 25th warp is the most similar warp yarn to the warp yarn in the frame (Figure 7(a)) labeled by the green line.



(a)



(b)

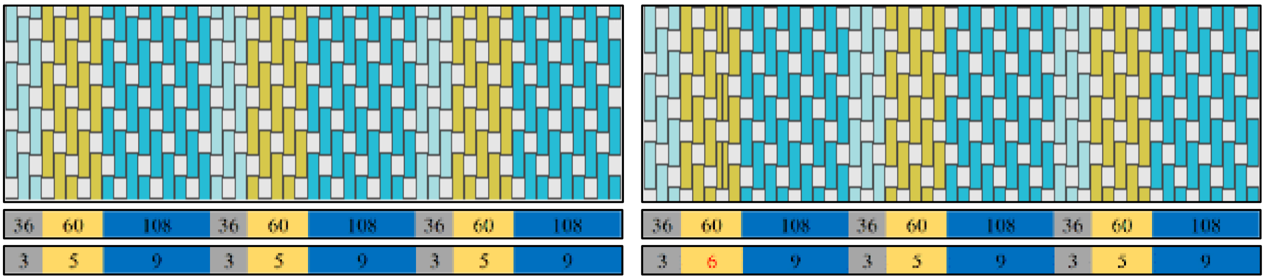
Figure 7. Image sittching result of two frames of fabric image (a) and (b).

3.4 Yarn layout proofing

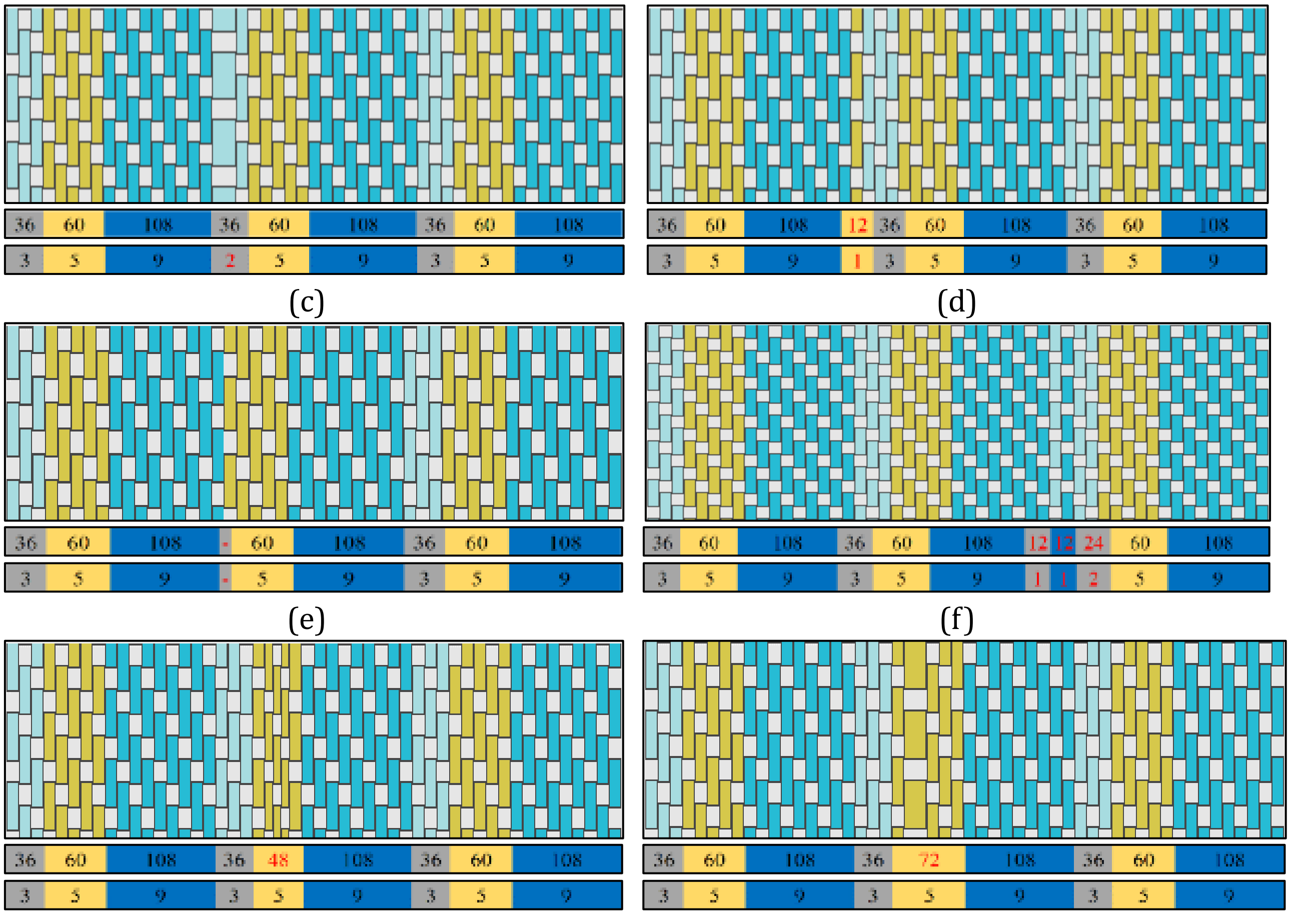
Warp vectors generation After the above processing, the strip images of the yarn-dyed fabric sample are transformed into two coded vectors: $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$, in purpose of covering all mistakes analyzed later. In these vectors, every element represents the region-pixel-width(rpw) and region-yarn-number(ryn) of a color region in the whole fabric strip sample. Specifically, element $v^d(i)$ represents the number of pixel columns in the i^{th} color region in the corresponding image; element $v^m(i)$ represents the number of warp yarns detected in the i^{th} color region. Accordingly, as standard data for yarn layout proofing, the reed draft in production is also transformed into region-pixel-width and region-yarn-number vectors: $\boldsymbol{t^d}$ and $\boldsymbol{t^m}$. In these vectors, every element represents a color region in one warp repeat. Also, element $t^d(i)$ represents the expected number of pixel columns and element $t^m(i)$ represents the number of warp yarns in the i^{th} color region in one warp repeat. For reed drafts used in production only have yarn-number information for color regions, $\boldsymbol{t^d}$ is generated from multiplying $\boldsymbol{t^m}$ by the mean pixel-width of a yarn in the image samples.

Yarn Mismanaged case analysis Generally, misarranged warp yarns in yarn-dyed fabric can be caused by the follow reasons: (1) missing or redundant slight warp yarns, (2) missing or redundant whole regions, (3) mis-sequenced yarn, (4) thick or thin reeding. Assume that we have rpw and ryn vectors for a correctly-arranged yarn-dyed fabric strip sample $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$, whose elements follow the loop order in $\boldsymbol{t^d}$ and $\boldsymbol{t^m}$, the above mistakes will cause different changes of the value and order circular in these vectors. Generally, mistake (1) causes value changes in $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$. While in some conditions, the reeder does not change the reed locations of the yarns after the missing or redundant ones (be ignored), thus the widthes of regions are not changed. In such conditions, mistake (1) only causes value changes in $\boldsymbol{v^m}$. Mistake (2) causes order circular changes in $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$. Mistake (3) causes both value and order circular changes in $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$. Mistake (4) causes only value changes in $\boldsymbol{v^d}$. In summary, misarranged warp yarns can change $\boldsymbol{v^d}$ and $\boldsymbol{v^m}$ respectively. To finish the Yarn layout proofing, one must comparing and contrasting the warp yarn vectors and the template vectors to locate the mistakes.

As introduced above, misarranged warp yarns cause three main mistakes in fabric appearance. Assume now we have a pair of templates as $\boldsymbol{t^d} = [36, 60, 108]$ and $\boldsymbol{t^m} = [3, 5, 9]$, and the warp vectors with no mistake should be $\boldsymbol{v^d} = [36, 60, 108, 36, 60, 108, 36, 60, 108]$ and $\boldsymbol{v^m} = [3, 5, 9, 3, 5, 9, 3, 5, 9]$. To simplify the example, the loop number of sample is valued as 3. Examples for vectors within the above mistakes are shown in Figure 8, where the red numbers indicate the mistakes location.



(a) (b)



(c) (d)

(e) (f)

(g) (h)

Figure 8. Illustration for different kinds of misarranged warp regions and their warp vectors (first row: $\boldsymbol{v}^m$; second row: $\boldsymbol{v}^m$): (a)Correctly arranged; (b)mistake (1): Redundant yarn; (c)mistake (1): missing yarn; (d)mistake (2): redundant region; (e)mistake (2): missing region; (f)mistake (3): mis-sequenced yarn; (g)mistake (4): thick reeding; (h)mistake (4): thin reeding.

Yarn Proofing Modeling Elements in the correctly arranged $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$ follow the loop order in $\boldsymbol{t}^d$ or $\boldsymbol{t}^m$. When misarranged warp yarns occur, the original vectors will be changed in some locations. Mathematically, a correctness vector of the warp yarns ranging can be described as the logical summation of two 0-1 vectors $\boldsymbol{w}^d$ and $\boldsymbol{w}^m$. These vectors have the same length of $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$. Specifically, the value of $w^d(i)$ and $w^m(i)$ (1 or 0) represents the i^{th} warp yarn region in $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$ is detected as the mistake position or not respectively.

For an input warp yarn vector couple $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$, the problem is modeled as mapping all the elements in $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$ to 0-1 vectors $\boldsymbol{w}^d$ and $\boldsymbol{w}^m$ respectively, finding all the 1 values that meet the follow conditions: (1) the length of every continuous 1 values fragment $\boldsymbol{r}^d{}_k$ and $\boldsymbol{r}^m{}_k$ is larger than a specified value δ_1; (2) $\boldsymbol{v}^d{}_k$ and $\boldsymbol{v}^m{}_k$, the corresponding values of $\boldsymbol{r}^d(i)$ and $\boldsymbol{r}^m(i)$ in $\boldsymbol{v}^d$ and $\boldsymbol{v}^m$, follow the loop order in template $\boldsymbol{t}^d$ or $\boldsymbol{t}^m$ within certain errors δ_2^d and δ_2^m.

The optimization model of yarn layout proofing is given as follow:

Objective function:

$$\underset{w^d,w^m}{\operatorname{argmax}} = \sum_{i=1}^{l^w}(w^d(i) \wedge w^m(i))$$

Constraint:

$$length(\boldsymbol{v_k^d}) > \delta_1 \quad k = 1,2,3 \dots k^d$$

$$length(\boldsymbol{v_k^m}) > \delta_1 \quad k = 1,2,3 \dots k^m$$

$$\exists\, j = 1,2,3 \dots l^t\colon \left|t_j^d(i) - v_k^d(i)\right| < \delta_2^d \;\; k = 1,2,3 \dots k^d \;\; i = 1,2,3 \dots length(\boldsymbol{v_k^d})$$

$$\exists\, j = 1,2,3 \dots l^t\colon \left|t_j^m(i) - v_k^m(i)\right| < \delta_2^m \;\; k = 1,2,3 \dots k^m \;\; i = 1,2,3 \dots length(\boldsymbol{v_k^m})$$

where l^w is the number of warp yarn regions in an input vector; $\boldsymbol{v}^d{}_k$ and $\boldsymbol{v}^m{}_k$ are calculated from $\boldsymbol{v}^d{}_k = F(\boldsymbol{v}^d, \boldsymbol{w}^d, k)$ and $\boldsymbol{v}^m{}_k = F(\boldsymbol{v}^m, \boldsymbol{w}^m, k)$ separately, where $F(\boldsymbol{v}, \boldsymbol{w}, k)$ is the function to find the position of the k^{th} sufficient-value-one-substring **(substrings of 1 but no adjacent element of value 1)** in vector $\boldsymbol{w}$, and return the substring in $\boldsymbol{v}$ at the same positions; k^d and k^m is the number of sufficient-value-one-substrings in $\boldsymbol{w}^d$ and $\boldsymbol{w}^m$ separately; l^t is the length of template $\boldsymbol{t}^d$ and $\boldsymbol{t}^m$; $\boldsymbol{t}^d{}_j$ and $\boldsymbol{t}^m{}_j$ is the circular shifts of vector $\boldsymbol{t}^d$ and $\boldsymbol{t}^m$ by j positions.

This model can be solved by an iterative algorithm as follow steps:

Step 1: Set starting value: w(0) = 0, k = 1, p = 1; set model parameters: δ_1, δ_2^d, δ_2^m; input yarn layout vectors $\boldsymbol{v}^d$, $\boldsymbol{v}^m$, and templates $\boldsymbol{t}^d$, $\boldsymbol{t}^m$; calculate $z = fix(\delta_1/l^t) + 1$; take $\{\delta_2^d, \boldsymbol{v}^d, \boldsymbol{t}^d\}$ and $\{\delta_2^m, \boldsymbol{v}^m, \boldsymbol{t}^m\}$ as $\{\delta_2, \boldsymbol{v}, \boldsymbol{t}\}$ to execute step 2 respectively;

Step 2: If $k \le l^v$, operate under follow cases in loop:

If $k \le l^t$:

If $w(k-1) = 1$ and $|v(k) - t(p)| < \delta_2$

$$w(k) = 1$$

$$p = \begin{cases} p+1 & p < l^t \\ 1 & p = l^t \end{cases}$$

$$k = k + 1$$

If $w(k-1) = 0$ and $\{\exists\, j = 0,1,2, \dots l^t - 1\colon \left|v(k+i-1) - t_{j,z}(i)\right| < \delta_2 \;\; i = 1,2,3 \dots \delta_1\}$

where $\boldsymbol{t}_j$ is the circular shifts of $\boldsymbol{t}$ by j positions, $\boldsymbol{t}_{j,z}$ is the 1-by-z tiling of $\boldsymbol{t}_j$; suppose $\boldsymbol{t} = [1, 2, 3]$, then $\boldsymbol{t}_1 = [2,3,1]$, $\boldsymbol{t}_{1,2} = [2,3,1,2,3,1]$.

$$w(k+i-1) = 1 \quad i = 1,2,3 \dots \delta_1$$

$$p = \{(j + \delta_1)\ mod\ l^t\} + 1$$

$$k = k + \delta_1$$

Else

$$w(k) = 0$$

$$k = k + 1$$

Step 3: Output $w^d \vee w^m$ as the yarn layout proofing result.

4 Results analysis and discussion

4.1 Algorithm analysis

In the proposed yarn segmentation of Part I, h, γ_1 and γ_2 make an influence on the warp yarn segmentation, when β_1 and β_2 affect the fabric image stitching. Hence, the effects of h, γ_1 and γ_2 are indicated by the error of the warp segmentation, and the effects of β_1 and β_2 are indicated by the error of the image stitching. It can be seen that all tubers h, γ_1, β_1 and β_2 make little influence on the system performance within the given range of variation. The system performance is sensitive to large changes of the tuner γ_2. The smaller and larger values of γ_2 cause the error of the warp segmentation to drop down to above 5%. Thus, the tuner γ_2 is considered as the main limiting factor for the system generalizability.

In the proposed warp region segmentation method of Part II, h, γ_1 and γ_2 make an influence on the warp yarn segmentation, when β_1 and β_2 affect the fabric image stitching. Hence, the effects of h, γ_1 and γ_2 are indicated by the error of the warp segmentation, and the effects of β_1 and β_2 are indicated by the error of the image stitching. In can be seen that all tubers h, γ_1, β_1 and β_2 make little influence on the system performance within the given range of variation. The system performance is sensitive to large changes of the tuner γ_2. The smaller and larger values for cause the error of the warp segmentation to drop down to above 5%. Because of its tolerance windows in the yarn segmentation process, the tuner γ_2 is considered as the main limiting factor for the system generalizability.

In this paper as the Part III, the proposed layout proofing algorithm has three main parameters: δ_1, δ_2^d and δ_2^m. δ_1 is the minimum region length of a region sequence without misarranged yarn. Based on the real production experiment, the region length of such regions sequence should be at least equal to one warp repeat. As result, δ_1 is set as the region length of one warp repeat, and the parameter δ_2^m, the tolerance of the ryn data noise, is set to zero. As for the tolerance of the rpw data noise, for the constraint of reed and fabric structure, the noise of the region width is always lower than 50% of the yarn width, this parameter is set to 50% of the yarn pixel width. All these fixed setting for all crucial parameters used during evaluation of the proposed algorithmic framework are shown in Table 1.

Table 1. Fixed setting for all crucial parameters used during evaluation of the proposed algorithmic framework

Parameter	Discussed in	Type	Effect	Value
h	Part I-Precise Warp segmentation	Tuber	The height of the sub-images	10.0
γ_1	Part I-Precise warp segmentation	Tuber	The span of LOESS algorithm	1.5
γ_2	Part I-Precise Warp segmentation	Tuber	The span of LOESS algorithm	1.5
β_1	Part I-Image stitching	Tuber	The height of the template image	2.0
β_2	Part I-Image stitching	Tuber	The width of the template image	4.0
w	Part II-Warp region segmentation	Tuber	Controling color histogram's size	0.05
τ_1	Part II-Rough region segmentation	Threshold	Inspecting regional boundries	0.95
τ_2	Part II-Rough region segmentation	Threshold	Inspecting regional boundries	0.40
τ_3	Part II-Precise warp region merging	Threshold	Removing regional boundries	0.90
δ	Yarn layout proofing	Threshold	The tolerable error of the region width	0.5

4.2 Experiment results

In practical situation, the layout proofing algorithm can be puzzled by the mistakes in warp region recognition. Even for a well-established warp region recognition algorithm, mistakes may still appear in a very low possibility, which cause the layout proofing algorithm predicting the correctly ranged warp region into an incorrect one. Thus, to demonstrate the effectiveness of the proposed layout proofing algorithm, the performance of the algorithm in two situations, i.e. ideal situation and actual situation, are discussed respectively.

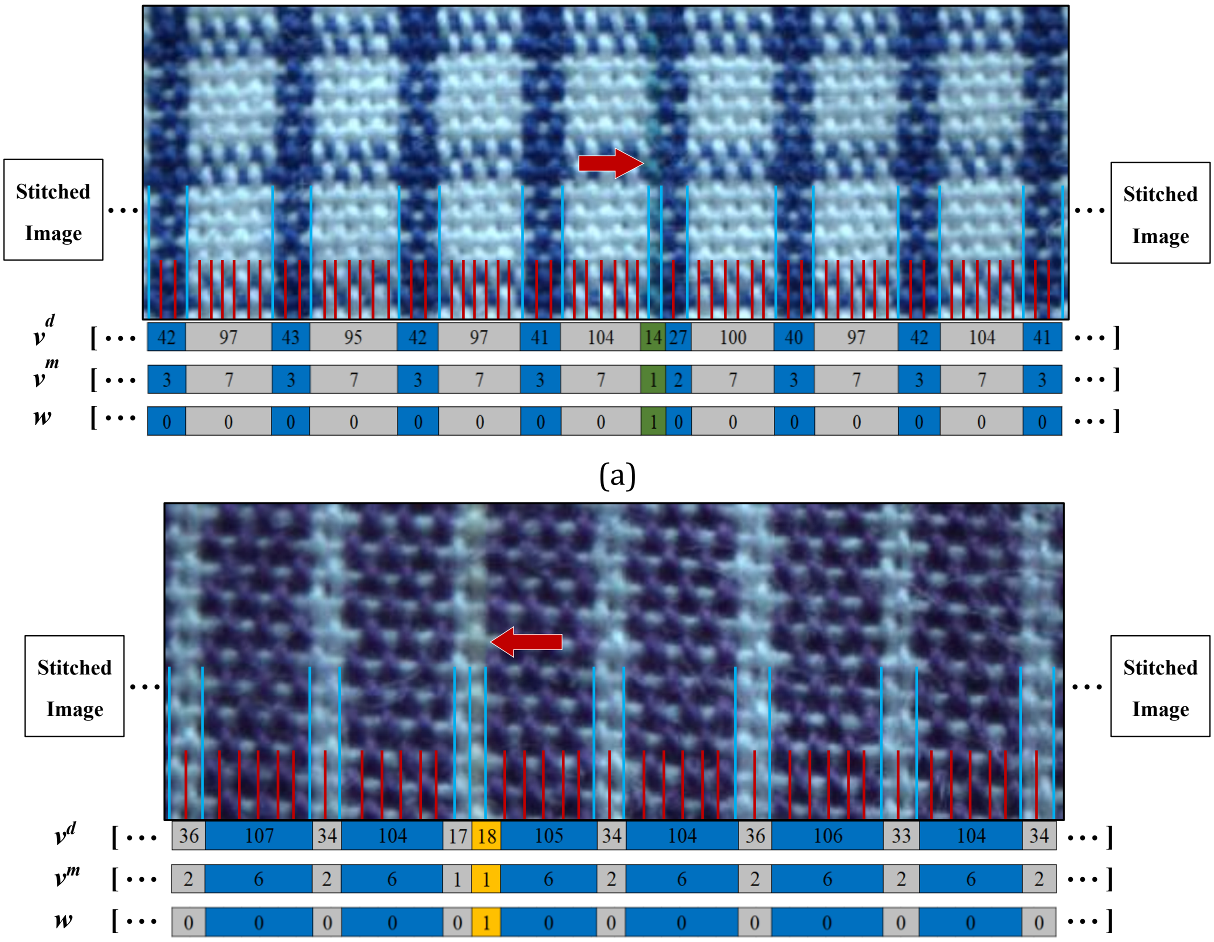
Ideal situation performance In ideal situation, there is no incorrectly recognized warp range existing, which can be easily expressed by a set of simulation fabric data as in Figure 8. The advantages of using the simulation data can be given as follows: (1) the input data (warp vectors) are easy to be widely simulated for they are just cyclic data combinations with describable disturbances; (2) the simulation data can sufficiently include all categories of the mistakes that need to be detected; (3) the simulation data possess excellent flexibility to guarantee the universality of the test. In this section, samples in the simulation data set are generated from the different kinds of mistakes proposed in Figure 8.

As given in Figure 8, the mistake elements located and shaped different between different mistake categories. When mistake (1) happens, rpw($\boldsymbol{v}^d$) does not change and the ryn($\boldsymbol{v}^m$) changes its value at the location corresponding to the location of the missing or redundant yarn. When mistake (2) happens, the warp vectors lost or obtain a new element at the specific location. When mistake (3) happens, the warp vectors get redundant elements and value changes at the same time. When mistake (4) happens, only $\boldsymbol{v}^d$ gets element value change at the location where the thick or thin reeding happens. The above mistakes can happen at a same location and generate a synthetic mistake. In summary, different categories lead to different changes in the warp vectors: length or element value.

In the experiments, more than 100 simulated samples are generated with different kinds of warp yarn arrangement and yarn diameters. To simulate the practical situation better, uniform noises are added in to the ryn($\boldsymbol{v}^m$), for the width of the warp regions fluctuates between a certain range caused by the real form of the fabric. Based on the proposed algorithm, as results, all the miss arranged yarns or warp ranges are detected and located precisely in the above simulated samples with a 100% accuracy, which verified the effectiveness of the proposed algorithm in the ideal situation.

Actual situation performance In actual situation, differing from the ideal situation, there may be a certain number of mistakes appearing in the warp vectors, which may be caused by the former progresses, i.e. the wrong segmented warp yarns or warp ranges. It is impossible for the layout proofing algorithm to distinguish the abnormal in the warp vectors between the former-progresses-caused ones and the misarranged-yarn-caused ones. Fortunately, the confusing mistakes happen in a low probability based on the algorithms proposed in our previous study, which can be totally considered as the misarranged warp regions by the proposed layout proofing algorithm and handled by the operator to recheck.

In this experiment, 10 actual fabric samples with specific misarranged warp regions are collected and fed into the whole proposed system. Take two samples as example as given in Figure 9, the input warp vectors $\boldsymbol{v}^d$, $\boldsymbol{v}^m$ and the proofing result vector $\boldsymbol{w}$ are illustrated. The locations of the misarranged warp regions are correctly detected as the 1 value location in $\boldsymbol{w}$, which are marked by the red arrows in the figures. As results, all the misarranged warp regions are detected and located precisely by the proposed system with a 100% accuracy. However, averagely 1.3% well-arranged warp ranges are wrongly recognized as the misarranged ones, which is caused by the former progresses discussed above. While in practical application, such results without neglecting the misarranged warp regions and a low misdetection rate are acceptable, which can provide an excellent guidance for misarranged warp regions detection.



v^d	[···	42	97	43	95	42	97	41	104	14	27	100	40	97	42	104	41 ···]
v^m	[···	3	7	3	7	3	7	3	7	1	2	7	3	7	3	7	3 ···]
w	[···	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0 ···]

(a)

v^d	[···	36	107	34	104	17	18	105	34	104	36	106	33	104	34 ···]
v^m	[···	2	6	2	6	1	1	6	2	6	2	6	2	6	2 ···]
w	[···	0	0	0	0	0	1	0	0	0	0	0	0	0	0 ···]

(b)

Figure 9. Illustration of one image frame with the misarranged warp yarn of two fabric samples (a) and (b), and their warp vectors $\boldsymbol{v}^d$, $\boldsymbol{v}^m$ and the proofing result vector $\boldsymbol{w}$.

5 Conclusion

In this paper, a yarn layout proofing method is proposed based on our previous study of the warp yarn segmentation and fabric image stitching methods proposed in Part I and warp region segmentation method proposed in Part II. By analysing the different styles of the misarranged warp yarns and their warp vectors, a warp arranging model is built and solved by an iterative algorithm to realize the warp yarn layout proofing. The experiment result shows that the proposed method can well detect mistakes of misarranged warp yarns in different styles stably and effectively.

Up to this time, this series of studies has realized the automatic detection of misarranged color warp yarns in yarn-dyed fabric. This system can further be combined with automatic manufacturing equipment to improve manual inspection efficiency and to enhance enterprise's automation level.

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