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Colourless and colourful digital design of jacquard textiles

DOI: 10.1533/9780857098702.80

Abstract: This chapter reviews practical research in colour design and, in particular, colour mixture theory and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode.

Key words: digital, jacquard, design, colour mixture theory, colour mode, colourless design.

5.1 Introduction

This chapter discusses practical research in colour design and, in particular, colour mixture theory and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode.

5.2 Colour mixture theory for digital jacquard textiles

In the design of digital jacquard textiles, the nature and principle of colour mixture appropriate for the fabric cannot be neglected. Not only do these principles govern the colour expression on the face of the fabric but they also advance the innovation of structural design methods for jacquard fabrics. The expression of woven patterns and the colours of jacquard fabric interlacing through warp and weft threads must be realised based on the woven construction and deployment of colour threads, both warp-wise and weft-wise. Generally, in traditional plane design mode, the number of mixed colours on the face of a jacquard fabric was less than 100, due to mutual covering effects caused in the fabric’s construction. Thus, the colour design of jacquard fabric was an experience-based undertaking, and research in colour mixture theory was irrelevant for jacquard fabric design.

However, with the proposed layered-combination design mode, especially for the full-colour compound structure design method, digital jacquard is able to express true-colour effects with millions of mixed colours. The colour performance of digital jacquard textiles can now exceed the scope that the eye can distinguish, and has surpassed the design competence
of skilled manual labour. Mastering the nature of colour mixing has become one of the most important factors in the design creation of digital jacquard textiles.

Research into the colour mixture of jacquard fabrics has taken two major directions: the first is colour simulation through a computer-based system on a fixed fabric structure; the second is simulation design of jacquard fabric based on limited primary colour threads. These two research directions aim to increase the design efficiency of jacquard fabric, yet are very much based on the traditional plane design mode of jacquard fabric. The first direction addresses the design problem of colour matching of jacquard fabric: based on a fixed fabric structure, computers can be used to simulate changing colour effects through the variation of warp and weft threads, without the need for actual production. Although the design efficiency of colour simulations of jacquard fabric has increased, colour mixture theory, due to the lack of innovation in fabric structure, is the same as that of traditional design methods for jacquard fabric. The second research direction focuses on the establishment of an ideal colour model with limited primary colours, targeting the design of jacquard fabric to imitate given images via the disposition of limited primary threads. At present, there are two types of proposed colour model, viz. primary colour model and designated colour model. The primary colour model involves part, or all, of the fixed primary colours of red, magenta, yellow, cyan, blue and green with the support of black and white. The designated colour model consists of changeable colours selected on the basis of the colour effect of an objective image, normally with 4–8 designated colours in the model. Due to the lack of design innovation in fabric structure, even when the colour model is in theory optimal, the available structure design fails to support it. To avoid the insufficiencies inherent in design application, the use of a colour table/chart has been proposed, i.e. designing and weaving fabric colour samples to form a fixed colour table/chart prior to the design of the fabric. However, such a method has been useful only for designing jacquard fabrics with the same fabric technical specification.

In terms of colour design theory, the simulative effect of jacquard fabric can be better realised by the use of more threads of primary colours. However, when more colours are used as warp and weft threads, the compound fabric structure becomes so complex that it is difficult to attempt. Therefore, a balance point between the number of primary colours and the design of the fabric structure should be considered for colour mixing on jacquard fabric. Such a balance point can be realised only through an innovative design of the fabric structure. Thanks to the proposed layered-combination design mode, restrictions in the structural design of jacquard fabric have been freed. Now, jacquard fabric is able to express millions of mixed colour effects accurately. Based on such an innovative structure
design method, the research into colour mixture theory for jacquard fabric now has very good application value and design compatibility.

The colour mixing of jacquard fabric is different from that of colour mixing in artworks created in other media, such as in painting, printing, or on the screen display of a computer. In terms of colour science, there are three typical colour mixture theories: the additive colour mixture of light (corresponding to a computer’s RGB digital colour mode); the subtractive colour mixture of pigment (corresponding to a computer’s CMYK digital colour mode); and optical colour mixture (with no corresponding digital colour mode) (Green, 1999). Essentially, additive and subtractive colour mixtures are physical phenomena. However, optical colour mixture is a kind of physiological phenomenon, i.e. it is a colour illusion caused by the visual deficiency of the human eye. In terms of the colour characteristics of jacquard fabric, its colour mixture is an optical colour mixture. Optical colour mixtures can be divided into two types, in terms of their application: juxtaposition mixture and rotatory mixture: the former is a kind of static spatial colour mixture, while the latter is dynamic. Since the colour mixture of jacquard fabric is a static phenomenon, it has to do with the theory of static colour mixture. Therefore, the colour mixing of jacquard fabric can be seen as a kind of juxtaposition mixture of optical colour mixture. The physical colour mixing principle is inadequate to explain the changes of colour on jacquard fabric. In order to investigate the changing rule of mixed colour and colour mode during the design process of jacquard fabric, the influences pertinent to the colouring effect of jacquard fabric (such as the design of the fabric structure, the disposition of the colour threads, and even the fabric technical specification itself) should be taken into account.

5.3 Structure and colour in digital jacquard fabrics

Naturally, the woven structure of jacquard fabric is the foundation for colour mixture theory since the colour mixing of jacquard fabric is based on a woven structure interlaced with warp and weft threads. For jacquard fabric, there are three types of compound structures: the juxtaposition and non-backed effect (Fig. 5.1 (a)), juxtaposition and partial backed effect (Fig. 5.1 (b) and (c)), and juxtaposition and backed effect (Fig. 5.1 (d)). In general, the fabric structure of jacquard fabric designed by the traditional plane design mode is of either backed or partial backed effect. The entire compound structures, such as weft-backed, warp-backed and double-layer structures, should be produced on the basis of a backed or partial backed structure. When designing fabric structures with a non-backed effect under the traditional plane design mode, the change rules of woven threads in the compound structure will be beyond control. Such compound fabric structures cannot be drawn on point paper manually. However, when designing
fabric structures under the digital layered-combination design mode, with the application of a full-colour compound structure, the resulting compound fabric structure shows a non-backed effect, enabling jacquard fabrics to express full-colour effects with the change of floating length of juxtaposed threads.

By nature, the layered-combination design mode for digital jacquard fabric is devised around the juxtaposition of coloured threads. The colour mixing of digital jacquard fabric is based on a full-colour compound structure in which the floats of colour threads arranged in juxtaposition can vary freely, whilst the non-backed structure effect remains unchanged. Figure 5.2 shows the basic principle of colour mixing and colour changing in a full-colour compound structure. The colouring model consists of four wefts and one warp that meet the technical requirements of structure digitisation for jacquard fabric design. The gamut weaves used for each thread in the compound structure can be easily established. Taking the brightness of a digital grey image as the standard, the replacement of the greyscales of the digital image and the gamut weaves can be processed efficiently. Combining several monochromatic single-layer structures can produce a colourful fabric with a compound structure. Since the colour mixing of digital jacquard fabrics regularly features a full-colour effect, it can be viewed as an artwork in

5.1 Colour effects of compound structures of jacquard fabric. (a) Non-backed; (b) partial-backed; (c) partial-backed; (d) backed.

5.2 Colour mixture principles of full-colour compound structure.
which the artifact is made through the digitisation of a woven structure. The mixed colour effect of digital jacquard fabric, with its interlacing of warp and weft threads, cannot be substituted by any other artistic means.

5.4 Colour mode changes in digital jacquard textile design

In addition to colour mixture, the change of colour mode as part of the design process of the layered-combination design mode of digital jacquard is of considerable interest. Figure 5.3 shows how any true-colour digital image can either be separated into several achromatic paths to form colourless grey-mode digital images, or be decolourised completely to produce a grey digital image without colour separation. Next, based on the brightness of the grey-scales, a colourless grey image can be designed into a single-layer fabric structure via structure digitising. After that, a compound structure can be created in appropriate proportions by combining several single-layer fabric structures. Finally, colourful digital jacquard fabric can be produced by the deployment of coloured warp and weft threads. The structure produced is capable of showing rich mixed colours, with its potential colour number reaching the mega level. In the whole design process of the layered-combination design mode, the colour mode originates from a true-colour effect digital image, to a grey effect digital image, and finally to black and white (in both single-layer and compound structure) reflecting a state of no colour in the eyes, but in the depth of the heart. By then, the compound structure is able to express millions of mixed colours similar to the ‘true colour’ effect of the original digital image.

Moreover, it should be noted that in the course of the layered-combination design mode, the shape and colour of the digital image are separated: the key is the digitised structure. When processing the structure design, only the shape of the digital image is used. The colour effect of the digital image
and the final colour effect of the digital jacquard fabric may either be the same or different, depending solely on the purpose of the design. Both colour simulative design and colour innovative design of digital jacquard fabric share the same colour mixture theory and colour mode changing performance.

5.5 Colour mixing in digital jacquard textile design

The colour mixture theory of woven fabric has to be established based on the employment of the limited colours of warp and weft threads. Among primary colour theories, the digital primary colour modes, both RGB and CMYK, can provide available references to the colour design because there is no existing colour mixture theory available specifically for designing digital jacquard fabric under layer-combination design mode. When designing simulative fabric, the CMYK digital colour mode, based on subtractive colour mixture theory and used for output of digital images, seems the optimal choice. Since the colour mixing of woven fabric is subject to optical colour mixture theory, research into the differences between subtractive and optical colour mixture is thus the key for digital jacquard fabric colour to reproduce accurate colour effects of digital images. Figure 5.4 shows the mixed colour effect of two contrasting colours with the same area and lightness. The resultant mixed colour, under subtractive colour mixture, results in black with the same area, in theory. Under optical colour mixture theory, however, the mixed colour effect is dark grey and the mixed area is the sum of the two original areas. For this reason, the colour mixing of digital jacquard fabric interlaced with warp and weft threads is a spatial colour mixture with no superimposition. The main characteristic of this kind of colour mixture is that, after colour mixing, the luminosity is invariable but the mixed area is increased. Therefore, colour saturation is reduced when mixing colour with warp and weft threads. Further, the available range of

![Image of colour mixing](image_url)
colour saturation and the scope of brightness of the mixed colours are both reduced.

With reference to the colour mixture theory stated earlier, when designing digital jacquard fabric in the layered-combination design mode, the resulting compound structure of jacquard fabric is capable of expressing millions of mixed colours based on its compound structure. If applying a non-backed compound structure, fine colour shading effects can be produced. However, the colour mixing of digital jacquard fabric formed by the deployment of warp and weft threads is different from that of RGB additive colour mixture, or of CMYK subtractive colour mixture. It is based on a 3-D woven structure that brings about a distinctive quality for digital jacquard fabrics and, therefore, the colour mixing of digital jacquard fabrics features the perfect integration of textile materials and woven fabric structures that cannot be imitated by other means of artwork. Similarly, the simulation design of digital jacquard fabric can produce only a similar, but not an exact, copy of the same colour effect, of the original digital images.

5.6 Design of colourless digital jacquard fabrics

Practical research into colourless digital jacquard fabric design was carried out to investigate the relationship of structural design and fabric effect towards the creation of an appealing colourless digital jacquard fabric. To this end, two requirements were addressed: the expression of the woven image and the capability of mass production.

5.6.1 Choice of digital images

There are no restrictions on the images that can be used for colourless digital jacquard fabric design. Abstract or objective images of any sort, such as portraits, landscapes, flowers, manuscripts, can all be selected for fabric design. However, given the black-and-white shading effect and the further technical analysis of structure, a portrait image is the optimal choice. If the simulative design of a portrait motif can be produced satisfactorily, the method of its structural design will satisfy the design of any other images. Conversely, however, even if the structural design method satisfies other images such as landscapes or calligraphy, it does not necessarily mean that it will be suitable for simulating portrait images (Zhou, 2007e).

5.6.2 Selection of structure design methods

The design of gamut weaves is the first stage in the course of structure design. Gamut weaves contain a series of derivative weaves based on primary weaves that feature similar weave characteristics. Thus, not only
can they be applied to set up corresponding weave-databases, but they can also be employed to design single-layer fabric structures. Theoretically, a primary weave of a simple satin weave can support $4 \times R! \times M_s \times M_w$ weave-databases, of which each has a maximum of $R \times (R - 2) + 1$ weaves (where $R$ refers to weave repeat, $M_s$ refers to the number of elementary satins that feature identical weave repeats but a different step number, and $M_w$ refers to the number of weaves via changing the weave starting point, $M_w = R$). Thus, in design practice, it is important to optimise the design method of the weave-database rather than establish all the weave-databases.

Taking 24-thread satin as an example, six kinds of satin weaves can be drawn as a primary weave under different step numbers (Fig. 5.5). In terms of weave effect, six kinds of 24-thread satin weaves can form three pairs: (a) and (d); (b) and (e); and (c) and (f). Each pair of weaves shares the same weave effect but different slanting directions of interlacing points. For a balanced distribution of interlacing points, the weave effect of (a), (b), (d) and (e) are preferred to (c) and (f) in Fig. 5.5. Thus, given the technical specification of the fabric in design practice, the weave in Fig. 5.5(a) is selected as the primary weave for designing gamut weaves and for establishing a corresponding weave-database.

Discounting the irregular design method, in which weaving points vary without rules, there are three design methods that can be used for designing gamut weaves: the three regular transition directions (vertical, horizontal and diagonal) for adding/reducing interlacing points. Each of them can be used to build corresponding weave-databases based on the same primary weaves. Figure 5.6 shows, for example, (from top to bottom) the gamut weaves designed through vertical transition, horizontal transition and diagonal transition based on the primary weave shown in Fig. 5.5(a). The value of adding/reducing interlacing points in each of these gamut weaves is the same, i.e. $M = R = 24$. Thus, the black-and-white gradation effects of the three series of gamut weaves are the same. When applying these three series of gamut weaves to the design of colourless digital jacquard fabric, the effects produced should, in theory, be the same if the digital images are the same. If there is a difference among the effects of the three digital jacquard fabrics produced, it could be concluded that the design method of the gamut weaves affects the fabric effect.
Comparison of effects in fabrics

Balanced interlacement is one of the key technical points for the production of jacquard fabric, and it must be fulfilled satisfactorily in any fabric structure design. Under the digital design approach, computer-aided design has replaced structure drawing on point paper: thus, the balanced interlacement of warp and weft is essentially now dealt with in the course of the design of gamut weaves. Figure 5.6 illustrates three series of gamut weaves designed from primary weaves of 24-thread sateen. The number of gamut weaves is 23 for each series. Reducing the value of interlacing points can enlarge the number of gamut weaves. When $M = 1$, the number of gamut weaves changes to 529, i.e. $R(R - 2) + 1 = 529$; when $M = 12$, the number of gamut weaves changes to 45, i.e. $2(R - 1) - 1 = 45$; when $M = 6$, the number of gamut weaves changes to 89, i.e. $2[2(R - 1) - 1] - 1 = 89$.

The number of gamut weaves is 23 in each weave-database used to design colourless digital jacquard fabric, with the same portrait and the same fabric technical specification. The thread density is 115 threads/cm in both warp and weft directions. The warp threads are black and weft threads are white. The fabric effects produced are shown in Fig. 5.7. Here (a) is the original digital image in grey colour mode; (b)–(d) show the fabric effect designed by using gamut weaves with diagonal, horizontal and vertical transitions, respectively. Taking the simulated effect as the criterion to evaluate overall effect, (d) is considered to be the best; (c) is the worst; and (b) is barely satisfactory, with an unbalanced interlacement of warp and weft threads that may well affect the efficiency of fabric production.
Further, it was found that the simulated effect of colourless digital jacquard fabric is determined by the expression of black-and-white shading reproduced on the face of the fabric; this was also manifested in the detail of the fabric structure. Figure 5.8 (a), (b) and (c) show detailed face effects produced with a diagonal, horizontal and vertical transition, respectively. Taking the reproduced black-and-white shading effect as standard: (a) is satisfactory; (b) has the worst simulated effect in light areas but is better in dark areas; whilst (c) has the opposite effect, having the worse simulated effect in dark areas but the best in the light areas. Since the three series of gamut weaves designed had the same black-and-white shading effects, it is apparent that the black-and-white shading effects of the final fabric can be affected by the three-dimensional woven structure used for production.

Additionally, since the design of colourless digital jacquard textile was based on a single-layer fabric structure, the face and back effects of the fabric were reversed, showing a negative effect. Figure 5.9 shows the details of the reversed sides of fabrics, showing the detailed back effect designed by (a) diagonal transition; (b) horizontal transition; and (c) vertical
transition. Compared with the black-and-white shading effect on the face side, (a) results in little difference; (b) results in an opposite effect to the face side, i.e. a worse simulated effect in dark areas but better in light areas; and (c) also results in an opposite effect to the face side, i.e. a worse simulated effect in light areas but better in dark areas.

The difference in the black-and-white shading effect observed on the face and reverse sides of the fabric suggest that the design of the gamut weaves has an impact on the black-and-white shading effect of jacquard fabric. The conclusion that can be drawn from this is that, in the course of black-and-white simulative design of colourless digital jacquard fabric, the black-and-white shading effect of gamut weaves cannot simply represent the shading of the final fabric because there is a gap between paper drawing and final woven structure.

5.6.4 Technical evaluation

The three series of gamut weaves share the same black-and-white effect; however, the black-and-white shading effects of the fabrics produced are very different. It is evident that there is mutual covering amongst neighbouring threads, and that this leads to the inaccuracy of the black-and-white shading effect. There could be two reasons for mutual covering: it could be caused by common weaving points existing in the weave structure, or it could be caused by juxtaposed threads due to overlong floats. Since common weaving points have been avoided in the course of gamut weaves design, the sole reason for mutual covering is juxtaposed threads due to overlong floats. Thus, the longer the float, the better the covering effect.

Figure 5.10 shows three methods of increasing weaving points. When using weft-face gamut weaves to design a woven structure, the mutual covering of threads was caused mostly in the weft direction, i.e. there was mutual covering between weft threads. As a result, the covering effects of (b) and (d) in Fig. 5.10 are worse than that of (c).
Similarly, Fig. 5.11 illustrates another three methods of adding weaving points. When using warp-face gamut weaves (a reverse effect of Fig. 5.10) to design a woven structure, the mutual covering of threads was caused mostly in the warp direction, i.e. there was mutual covering between warp threads. In this case, the covering effects of (b) and (c) in Fig. 5.11 are worse than that of (d).

In brief, the lesser the mutual covering caused among threads in a fabric structure, the better the effect of black-and-white shading reproduced on the fabric. Table 5.1 shows the relationships between weave structures and black-and-white shading effects of designed fabric that coincide with the

<table>
<thead>
<tr>
<th>Character of gamut weaves</th>
<th>Light areas</th>
<th>Dark areas</th>
</tr>
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<tbody>
<tr>
<td>Diagonal transition</td>
<td>Satisfactory</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Horizontal transition</td>
<td>Worse</td>
<td>Best</td>
</tr>
<tr>
<td>Vertical transition</td>
<td>Best</td>
<td>Worse</td>
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Note: black warp and white weft.
results of actual design theory in practice. If the arrangement of threads is revised so that the warps become white and the wefts become black, the relationship between weave structures and the black-and-white shading effect of the designed fabric also needs to be reversed. Moreover, since the change of warp and weft density may also affect the covering effect of the fabric, the design of gamut weaves needs to be considered for the distribution of grey-scales in the digital image when processing a simulation design of colourless digital jacquard fabric.

5.7 Design of colourful digital jacquard fabrics

By using the layered-combination design mode for digital jacquard fabric, it is possible to produce jacquard fabric featuring a rich mixed colour effect by the combination of several single-layer structures. The colour expression of colourful digital jacquard fabric distinguishes itself from that of traditional jacquard fabric in two aspects: firstly, by the increased number of colours that can be produced (now at a mega level) and, secondly, the capability of expressing a multicoloured shading effect. As already mentioned, this study was carried out to explore the relevant relationships between structure design/combination methods and final fabric effects. Additionally, taking the smooth colour shading effect of digital jacquard fabric as an objective, an optimal structure design/combination method has been proposed. Thus, this study provides the essential technical references for the design creation of colourful digital jacquard fabric.

5.7.1 Choice of digital images

There is no particular limitation on the selection of image for colourful digital jacquard fabric design. A portrait image was selected as the optimal expression of colourful shading effects and structural characters due to the fine and smooth colour shading effect it portrays. As long as the simulative design of a portrait is satisfactory (in both the aspects of colour and pattern), the structural design method can be applied to other digital images.

5.7.2 Selection of structure design methods

Multicoloured jacquard fabric must be designed with a complex compound weave structure. Traditional complex compound weave design was approached by the combination of simple weaves in single-weave design mode. However, in digital jacquard textile design, the combination of single-layer structures has replaced the design process of single complex weave design. According to the combination principle of fabric structure, neighbouring threads constructed in the woven structure produce only two basic
effects, viz. the juxtaposition effect (a non-backed structure effect) and the mutual covering effect (a backed structure effect). Therefore, the generation of a non-backed or backed effect after the weave combination needs to be thoroughly understood for the design of gamut weaves and the combination of single-layer fabric structures. In addition, since the combined effect of primary weaves may represent the combination of gamut weaves in the same weave-database, it can be concluded that, when combining two single-layer structures designed by backed effect weaves, the compound fabric structure will also exhibit a backed fabric effect. On the other hand, when two single-layer structures designed with non-backed effect weaves are combined, the compound fabric structure may show a partial backed fabric effect, i.e. both backed effect and non-backed effect appear on the face of the fabric at the same time. Figure 5.12 shows four primary weaves of 24-thread sateen designed by displacing the starting point of the original primary weave. It can be used to establish four weave-databases for further design practice.

5.7.3 Comparison of effects in fabrics

In terms of the design principle of the layered-combination design mode for digital jacquard textile, any colourful digital image can be separated into four grey layers (representing CMYK, respectively). If the four series of gamut weaves that are designed on the basis of the four primary weaves in Fig. 5.12 are applied to such four grey layers, to design single-layer structures, three combination methods are available to combine these four single-layer structures to form a compound one. The first method is the combination of the four single-layer structures designed with the same gamut weaves, used repeatedly four times. The resultant fabric effect is shown in Fig. 5.13 (a). The mutual covering effect amongst juxtaposed weft threads dominates the face effect of the fabric in which the weft threads with shorter float are covered by those with a longer float. The second method is the combination of four single-layer structures designed with two
series of gamut weaves (pairing) which are used twice. The two series of
gamut weaves in different weave-databases have the same original primary
weave but have different weave starting points, i.e. the original primary
weave and its starting point are shifted 12 points/threads. The fabric effect
produced is shown in Fig. 5.13 (b) in which the mutual covering effect and
no-covering effect are both shown on the face of the fabric, at the same
time. Compared with the original digital image, the colour reproduction in
the area of the no-covering structure effect is better than that in the area
of the mutual covering structure effect. The third combination method is
the combination of single-layer structures designed with the four series of
gamut weaves which have the same original primary weave but different
starting points, i.e. original primary weave, 6 points/threads shifted, 12
points/threads shifted, and 18 points/threads shifted. The resultant fabric
effect is shown in Fig. 5.13 (c) in which the mutual covering effect and the
no-covering effect are shown on the face of the fabric at the same time.
Compared with the original digital image, the area of the no-covering struc-
ture effect seems to feature better colour reproduction than that in the area
of the mutual covering structure effect. Further, during fabric production,
a serious problem was generated, i.e. a regular slanting effect of weft threads.
This phenomenon seriously affected production efficiency.

5.7.4 Design experiments and technical evaluation

In order to identify the reasons behind the colour deviations caused in
simulative design of colourful digital jacquard fabric, further design prac-
tices were considered (see below), with the aim of reproducing the ideal
effect of smooth colour shading of the digital image. The same gamut
weaves method and the combination method of single-layer fabric
structures were applied, just as they were in Fig. 5.13 (b), i.e. the method consists of pairing gamut weaves and pairing weave-databases. In order to assess the fabric effects generated from compound fabric structures, the image selected for design practice had a smooth colour gradation. As a result, the fabric produced exhibited the defect of broken streaks (Fig. 5.14). Thus, it can be concluded that shortcomings in the structure design are the major reasons leading to the generation of the broken streaks which, in turn, caused the colour deviation in the simulative design of digital jacquard textile.

To identify the main reason for the broken streaks, experimental research was carried out to inspect the combination effect between two series of gamut weaves. Figure 5.15 shows the basic gamut weaves and Fig. 5.16 shows the joint gamut weaves designed by shifting six points from the original starting point. When using these two series of gamut weaves to design four single-layer fabric structures, the basic gamut weaves were applied twice to design two single-layer structures arranged in odd layers, while the joint gamut weaves were applied to two even layers.

After the combination of the four single-layer fabric structures, a compound fabric structure was formed in which two single-layer structures designed from basic gamut weaves were located in the odd layers (i.e. the
first and third layers), while another two single-layer structures designed from joint gamut weaves were located in the even layers (i.e. the second and fourth layers). In order to inspect the combination effect of the fabric produced, an experiment was carried out to ascertain the detailed effect of compound weaves combined from basic and joint gamut weaves. Figure 5.17 shows the combination effect of the first weave of basic gamut weaves and joint gamut weaves in a two-layer combination. Due to the use of the same combination method, i.e. the same starting point and same gamut weaves, the compound structure effect of this two-layer combination is similar to that of the four-layer combination. Careful examination discovered that the mutual covering effect and no-covering effect exist at the same time in compound weave effects. As shown in Fig. 5.17, the compound weaves before the mark (vertical line) show a non-backed compound effect while the compound weaves after the mark indicate a partial backed compound effect.

The results obtained from practical research into the combination of gamut weaves indicated that, when two series of gamut weaves are combined (and in which one series of the gamut weaves are designed by shifting the starting point of the other), the compound fabric structure shows both the mutual covering effect and a no-covering effect on the face of fabric at the same time.

In order to reduce or eliminate the broken streaks caused in compound fabric structures, further design experiments were conducted to investigate the main reasons that led to the generation of these broken streaks. Taking 12-thread satin as an example, 12 kinds of gamut weaves and weave-databases were created by changing the starting point and by different methods of adding interlacing points. The effects of gamut weaves are shown in Appendix 1, section A1.1, in which six kinds of gamut weaves/weave-databases, from N12-3w41-1 to N12-3w41-6, were designed by changing the starting points of primary weaves on the basis of gamut weaves N12-3w41. Two kinds of gamut weaves/weave-databases, N12-3w-z41 and

5.16 Effects of joint gamut weaves designed by shifting the starting points.
5.17 Combined effects of first basic gamut weave and joint gamut weaves.
N12-3w-z41-11, were designed by changing both the starting points of the primary weaves and the insert directions of the interlacing points, i.e. the insert direction of the interlacing points of N12-3w-z41 is left, while that of N12-3w-z41-11 is right. Two kinds of gamut weaves/weave-databases, N12-3w-z41-9 and C12-3w-z-y41-9, were paired. N12-3w-z41-9 was designed by changing the starting point of the primary weave and the insert direction of the interlacing points (similar to the design method of N12-3w-z41-11 described above). C12-3w-z-y41-9 was designed by changing the starting points of the primary weaves and the insert direction of the interlacing points (which was changed to right-left-right, in order to reduce the covering effect caused in the fabric structure).

As shown in Table 5.2, seven design experiments were conducted with the aim of reducing broken streaks, all with the same fabric technical specification of a four-layer combination but with different methods for gamut weaves design and for single-layer fabric structure combination. In the experiments A to D, the design methods for the gamut weaves were similar, i.e. same inset direction of interlacing points but different starting points. As a result, the combination effects of the single-layer fabric structures in the experiments were different. After weaving the sample, the broken streaks generated on the face of the fabrics of the four swatches were more pronounced, and the fabric effect was seriously affected. Furthermore, the position of the broken streaks on the fabric was random.

In experiment E, the insert directions of the interlacing points of the gamut weaves was changed to right and left, whereby the broken streaks caused on the face of the fabric were visibly reduced. In experiment F, the starting point was changed further, and the swatch produced had fewer broken streaks compared with the experimental swatches A to D, but more than that of experiment E. In experiment G, based on the design method of gamut weaves of experiment F, the insert direction of the interlacing points of gamut weaves was changed into right-left. The fabric effect thus produced resulted in only a few broken streaks. Figure 5.18 shows the partial fabric effects of most (serious), some (less serious) and few (light) broken streaks produced in the design experiments. Figure 5.18 (a) indicates the fabric effect with most broken streaks. It was found that the broken streaks in the partial area on the face of the fabric were connected; they appear to have formed a backed structure that led to a serious covering effect in the compound structure. Subsequently, the colouring effect of the jacquard fabric deviated more from the original image. Figure 5.18 (b) presents a fabric effect with some broken streaks. These broken streaks exhibited clearly on the face of the fabric and have a mild influence on the fabric structure, but a more pronounced colour effect. Figure 5.18 (c) shows the fabric with few broken streaks, and the fabric structure is less affected when compared to the colour effect of fabric; however, the colour shading effect between the two colours is still unsatisfactory.
Table 5.2 Results of design experiments to reduce broken streaks

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Gamut weaves and weave-databases</th>
<th>Insert direction of interlacing points (odd/even layers)</th>
<th>Diagram of combination method</th>
<th>Broken streaks/colour influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>N12-3w41-1/N12-3w41/N12-3w41-1/N12-3w41</td>
<td>Right</td>
<td></td>
<td>More/serious</td>
</tr>
<tr>
<td>B</td>
<td>N12-3w41-3/N12-3w41/N12-3w41-3/N12-3w41</td>
<td>Right</td>
<td></td>
<td>More/serious</td>
</tr>
<tr>
<td>C</td>
<td>N12-3w41-2/N12-3w41/N12-3w41-3/N12-3w41-1</td>
<td>Right</td>
<td></td>
<td>More/serious</td>
</tr>
<tr>
<td>D</td>
<td>N12-3w41-3/N12-3w41/N12-3w41-5/N12-3w41-2</td>
<td>Right</td>
<td></td>
<td>More/serious</td>
</tr>
<tr>
<td>E</td>
<td>N12-3w-z41-11/N12-3w-z41-11/N12-3w-z41</td>
<td>Left/right</td>
<td></td>
<td>Few/light</td>
</tr>
<tr>
<td>F</td>
<td>N12-3w-z41-9/N12-3w-z41/N12-3w-z41-9/N12-3w-z41</td>
<td>Left/right</td>
<td></td>
<td>Some/medium</td>
</tr>
<tr>
<td>G</td>
<td>C12-3w-z-y41-9/N12-3w-z41/C12-3w-z-y41-9/N12-3w-z41</td>
<td>Left/right-left</td>
<td></td>
<td>Few/light</td>
</tr>
</tbody>
</table>

Note: gamut weaves and weave-databases are presented in Appendix 1.
Additionally, it was found that the broken streaks generated on the face of the fabrics were distributed randomly, and the position of the broken streaks varied with the change of design methods of the gamut weaves and the combination methods of the single-layer fabric structure. As shown in Fig. 5.18, the broken streaks of the three fabric swatches designed by the three methods were distributed differently on the face of the fabric. To help identify the major reason for the broken streaks, the combination effects of the four primary weaves of the four series of gamut weaves in the seven design experiments, from (a) to (g), are presented in Fig. 5.19. Obviously, the combination effect of primary weaves can affect the woven texture of jacquard fabric. However, through the change of combination method of the single-layer fabric structure, the generation of broken streaks can be reduced, though not removed completely.

Since all the broken streaks were located at the junction area between the covering and non-covering effect of compound weave structures, it is implied that the proportion of backed structures and non-backed structures would vary when the single-layer structures designed by different gamut weaves and with different combination methods were combined. Figure 5.20 shows the combination effect of the first weave of basic gamut weaves and the entire joint gamut weaves in design experiment E. In comparison with the results in Fig. 5.17 (that was combined by the first weave of the

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5.18 Fabric effects of broken streaks generated in the design experiments. (a) Most (serious); (b) some (less serious); (c) few (light).
5.19 Combined effects of four primary weaves of four series of gamut weaves.
basic gamut weave and all the joint gamut weaves in design experiment B),
the non-backed compound weaves before the vertical mark in Fig. 5.20 are
more than those in Fig. 5.17. In addition, the backed effect of the compound
structure in Fig. 5.20 is actually more of a half-backed effect, i.e. neighbour-
ing threads cover only one side while the other side exhibits a non-backed
effect. As a result, the compound structure shown in Fig. 5.20 is steadier
than that of Fig. 5.17.

Based on the results of the design experiments stated in Table 5.2 and
the related technical analysis, the conclusion can be drawn that the broken
streaks exhibited on the face of the fabric in digital colourful jacquard fabric
design has to do with the design method of the gamut weaves. When apply-
ing gamut weaves created by a normal design method to design a single-
layer fabric structure, the broken streaks cannot be eliminated on the face
of the fabric after combination. By changing the insert direction of the
interlacing points during gamut weave design, the generation of broken
streaks can be reduced, but they cannot be avoided completely. It could be
argued that the design experiments were conducted only with a simple
colour shading effect as the sole and optimal method for verifying the
broken streaks caused in digital colourful jacquard fabric design under a
layered-combination design mode. When designing fabric with complex
images, because of the richer and more staggered mixed colours on the face
of the fabric, broken streaks may be avoided.

5.7.5 Design practice with full-colour compound structures

Compared with the original digital image, the colour effect of a jacquard
fabric produced will deviate due to the existence of broken streaks caused by
mutual covering effects in a compound fabric structure. However, since more
colour deviation was produced in the area dominated by a backed structure,
and less so in the area dominated by the non-backed structure, if mutual
covering effects amongst juxtaposed threads can be avoided during the
design process of compound fabric structures, the simulative design of col-
ourful digital jacquard fabric should be able to be realised. In fact, the design
method for a full-colour compound structure offers the capability of design-
ing a non-backed and full-colour compound structure. In theory, it meets the
requirements of simulation design of colourful digital jacquard fabric.

Design of full-colour weaves

Taking 12-thread satin as an example, and based on experiment G in
Table 5.2, full-colour technical points were setup for a basic primary weave
and a joint primary weave, respectively, in accordance with the design prin-
ciples and methods of a full-colour compound structure. The position of
5.20 Combined effects of first basic gamut weaves and joint gamut weaves.
technical points is shown in Fig. 5.21. The basic gamut weaves produced were Ac12-3w-z-y41, while the joint gamut weaves were Ac12-3w-z-y41-9 (see panel (o) Appendix 1, section A1.1). Two series of gamut weaves have the same technical parameters, i.e. adding points once is 3, insert direction is right-left or left-right, weft-wise, and the number of gamut weaves for each is 37.

Design practice of full-colour shading

The differences in fabric effects between digital jacquard and traditional jacquard fabric relate to the substantial increase of mixed colour numbers and the capability of expressing a print-like colour shading effect. Therefore, the major challenge is to design and produce a kind of colour palette with full-colour changing effects similar to that of a spectrum colour effect. The superior design effect of digital jacquard fabric per se is a fine illustration of the superiority of digital jacquard fabrics over those designed and produced by the traditional plane design method.

By using basic and joint gamut weaves alternately to design single-layer fabric structures, the completed compound fabric structure, in which the odd number layers were designed by basic gamut weaves while the even number layers were designed by joint gamut weaves after combination, has made possible a smooth colour shading effect on the face of jacquard fabrics without broken streaks. Figure 5.22 shows the fabric effect of a full-colour shading palette designed with four primary colours, viz. three basic coloured threads (cyan, magenta and yellow), and one black thread. Following the design method of a four-layer full-colour compound structure, a full-colour shading palette with three primary colours was realised, to which black can be applied to adjust colour brightness. The structure design method started by designating two primary weaves. The full-colour points were designed first, then basic and joint gamut weaves were designed, respectively, on the basis of the two primary weaves. Finally, basic and joint gamut weaves were applied alternately to design four single-layer fabric structures. Basic gamut weaves were used for the odd numbered fabric
structural design, while joint gamut weaves were used to design the even numbered fabric structures. After combining the four single-layer fabric structures, in an order of 1 : 1 : 1 : 1, the compound fabric structure obtained was capable of expressing a full colour shading effect. Even if the colours of the threads were changed, the colour shading effect remained unchanged in the compound fabric structure. Therefore, designing a full-colour compound structure under the layered-combination design mode met the technical requirements of designing digital jacquard fabric with a full-colour shading effect. Indeed, this design mode enabled digital jacquard fabric to be produced with a print-like colour effect that was impossible to attain under the traditional plane design mode. Section A3.1 in Appendix 3 shows more creations with a full-colour shading effect.

5.7.6 Summary

Through design experiments on colourful digital jacquard fabric, especially those on fabric structure, the major reason for generating broken streaks was identified and an optimal solution was found. The results suggested that the design methods of gamut weaves and the combination methods of single-layer fabric structures have laid the foundation for colourful digital jacquard fabric design and production. The compound structure of jacquard fabric combined with gamut weaves designed by the normal method has the capability of expressing a mega level of mixed colours on the face of the fabric. However, broken streaks cannot be avoided during the design process. When the full-colour compound structure design method is used, through the setting of full-colour technical points on the gamut weaves, the digital jacquard fabrics produced were capable of expressing fine colour shading and accurate colouring effects. For these reasons, when approaching a design creation with the aim of attaining the true-to-original effect of a digital image, the full-colour compound structure is the optimal choice. When designing digital jacquard fabric to show innovative effects, both half non-backed and non-backed compound structures are capable of expressing the unique woven effect of jacquard fabric that cannot be
imitated by any other means of art. Gamut weaves designed by the normal method are regarded as unsuitable for design creations with either simulative or innovative effects, due to the generation of too many broken streaks in the compound fabric structure.

Table 5.3 summarises the findings of design practices for colourful digital jacquard textiles.

<table>
<thead>
<tr>
<th>Broken streaks/colour influence</th>
<th>Effect of compound structure</th>
<th>Corresponding experiments</th>
<th>Recommended design application</th>
</tr>
</thead>
<tbody>
<tr>
<td>More/serious</td>
<td>Forming backed area</td>
<td>A–D</td>
<td>Unfavourable</td>
</tr>
<tr>
<td>Some/medium</td>
<td>Individual broken streaks</td>
<td>F</td>
<td>Unfavourable</td>
</tr>
<tr>
<td>Few/light</td>
<td>Half-backed structure</td>
<td>E and G</td>
<td>Innovative effect</td>
</tr>
<tr>
<td>None/none</td>
<td>Non-backed</td>
<td>Full-colour shading</td>
<td>Simulative or innovative effect</td>
</tr>
</tbody>
</table>

5.8 Conclusion

This chapter has presented the most important part of our research into digital jacquard textile design. Since the layered-combination design mode is an original contribution to the design of digital jacquard textiles, the technical problems discovered in the design experiments are unprecedented. These problems relate to colourless and colourful digital jacquard textile design, such as the balanced interlacement required in fabric production and the broken streaks caused in compound structures. Through a series of experimental research and analysis of the results, the key innovation points of digital jacquard textile design pertaining to the design of colour and structure, as well as the relationship of fabric structure design and its colour expression, have been identified. In addition, the design concept, design principles and design methods proposed in the theoretical research have proved to be of tremendous benefit to the innovation of jacquard textile design. The results obtained from both experimental research in this chapter and the theoretical research in Chapter 3 have laid a solid foundation for the design creations of creative digital jacquard fabrics under the layered-combination design mode.

5.9 References and further reading


Innovative jacquard textile design using digital technologies

Wang, X. Q. and Ng, M. C. F. (2006), *Weaving Seamless Bags*, Overall Grand Award in the 8th International Foundation of Fashion Technology Institutes (8th IFFTI) Design Competition, North Carolina, USA.

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