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An Integration of Design and Production for Woven Fabrics Using Genetic Algorithm

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1. Introduction

Nowadays, the enterprises all over the world are approaching toward globalizing in design and production in order to be more sustainable. Integration of interior divisions in a company or cooperation among different companies worldwide is of great importance to the competence enhancement for entrepreneurs. There have been a variety of developed applications to integrating different divisions (Cao et al., 2011) (Yamamoto et al., 2010). Moreover, the range of R&D cycle for textiles is much narrowed than ever. It is necessary for an enterprise to afford the demand of marketing change in small quantity and large variety for the commodity. Thus, it is crucial for textile manufacturer to integrate the design and production processes.

Generally speaking, at the very beginning a piece of fabric appeals to a consumer by its appearance, which is related to the weave structure and the colors of warp and weft yarns. Next, the characteristics, e.g., the permeability, the thickness, the tenacity, the elongation et al. of the fabric are required. Finally, the price of the fabric is used as an evaluation basis, by comparing which to the above-mentioned items (i.e., the outlook and the characteristics), the value of the fabric can thus be defined and determined. If the value is satisfactory, the fabric will be accepted by the consumer. Otherwise, it will become a slow-moving-item commodity.

It is essential for the fabric with good quality to be of appropriate weaving density except being equipped with satisfactory pattern. If the weaving density is too less, the fabric will seem obviously too sparse to have good enough strength. The more weight consumption of the material yarns is, the higher cost needed for the manufacturing of a piece of fabric is. Thus, it is a crucial issue for a designer to make a good balance between the cost and the essential consumption of the material yarns during woven fabric manufacturing.

Woven fabric is manufactured through the interlacing between the warp and weft yarn. The pattern of the woven fabric is illustrated through the layout of the different colors of the warp and weft yarn. Therefore, the application of computer-aided design (CAD) (Dan, 2011) (Wang et al., 2011) (Liu et al., 2011) (Gerdemeli et al., 2011) (Mazzetti et al., 2011) to simulated woven-fabric appearance and to the other aspects has been a major interesting research in recent years and various hardware and software systems are now available on the market for widely commercial applications. Until these systems became available, a considerable amount of time and money had been needed to show designers' ideas of fabric design in pattern (fabric sample) form. Probably only 15-20% of the patterns produced would have been approved for production by the sales department or the customers or both. Thus design can be a very expensive exercise for manufacturers engaged in the fancy woven fabric market. The introduction of CAD to textiles has provided a major breakthrough in multicolor weave design. With the help of CAD, designers can display, examine, and modify ideas very quickly on the color monitor before producing any real fabrics. Thus CAD allows a greater scope for free creative work on the part of designers without incurring a large cost increase. CAD allows a greater flexibility in the designer's work, and the designer's creativity is more effectively used.

A designer can do a weave structure design by using his/her inspiration. However, for a designer it can happen to run out of his/her creativity for pattern design from time to time. Though the CAD is becoming more and more applicable to the pattern design (Hu, 2009) (Zhang et al., 2010) (Penava et al.,2009) it has not yet become a complete tool to the textile designer because of limits to the function of color and material yarn selecting that can be created automatically. Up to the present, designers have got to be satisfied with a limited function of their own chosen color and material yarn recently available to display the simulation of the fabrics.

There are huge amount of researches on the weave structure of woven fabric. Griswold (Griswold, 2011) proposed algorithms on using Boolean operations in weave pattern design. Rasmussen (Rasmussen, 2008) discusses the theory of binary representation of fabric structures and the possibilities of weave category in order to design families of weave patterns. Rao et al. (Rao et al., 2009) developed 3-D geometric models for the morphological construction of fabrics with the unit-cells of four harness, five harness, and eight harness. Shinohara et al. (Shinohara et al., 2008) proposed a novel automatic weave diagram construction method from yarn positional data of woven fabric. Ozdemir et al. (Ozdemir et al., 2007) developed a method to obtain computer simulations of woven fabric structures based on photographs taken from actual yarns along their lengths. On the other hand, weave pattern design will benefit from some theoretical studies on binary matrices, e.g., pattern mining techniques from binary data. Ma et al. (Ma et al., 2011) proposed an encoding algorithm to reveal the hidden information in the binary matrix of a weave pattern so as to obtain a solution to determine features of the weave pattern. It enables the possibility to quickly produce required weave geometries and weave textures at different levels of detail.

In order to go beyond the simulation function of a conventional CAD system, a design system, which can generate a variety of patterns for a designer to evaluate each of them and scoring them by preference, is of great value to be created and developed. Such a system is developed by using genetic algorithm in this study. Genetic algorithm (GA) is powerful and broadly applicable stochastic search and optimization techniques based on principles from evolution theory. GA has widely been applied in varieties of fields, e.g., CAD/CAM integration (Ahmad et al., 2011), electromechanical product design (Yang et al., 2011), Process planning (Salehi et al., 2009), information management optimization (Wei et al., 2009), and manufacturing cycle cost finding (Deiab et al., 2007). Through the assistance of the GA-developed system in this study, a fabric designer can proceed with the design process of weave structure more flexibly and effectively. With the help of GA-based CAD, a satisfactory creative pattern, which is of a specific weave structure with certain colors of warp and weft yarn, can be obtained.

Once the pattern design is determined, the characteristics (e.g., the thickness, the permeability et al.) need to be set for the next. Another Search system based on GA is developed for acquire weaving parameters as well. With this system, a fabric designer can efficiently determine weaving parameters to help manufacture the fabrics of required characteristics.

With GA-based design and production system, a fabric designer can efficiently determine the warp (or weft) yarn color, weave structure and the required weaving parameters (e.g., yarn count N_1, N_2, and weaving density n_1, n_2 of warp and weft yarn) for manufacturing satisfactory fabric. Thus, the design and production divisions can be integrated together. The running out of creative inspiration for a designer can be eliminated. The system can provide several appropriate combination sets of layout parameters which can meet a designer's satisfaction on the appearing pattern of the fabric and the demand of weaving parameters which can produce the fabric on expected material cost without lab manufacturing in advance. The construction of the integrated system for design and production is described as follows.

2. Framework of integrated system for design and production

As shown in Figure 1, the system consists of two major components, i.e., the search mechanisms for weaving parameter and weave structure, and the user interface. Each of them is described briefly as follows.

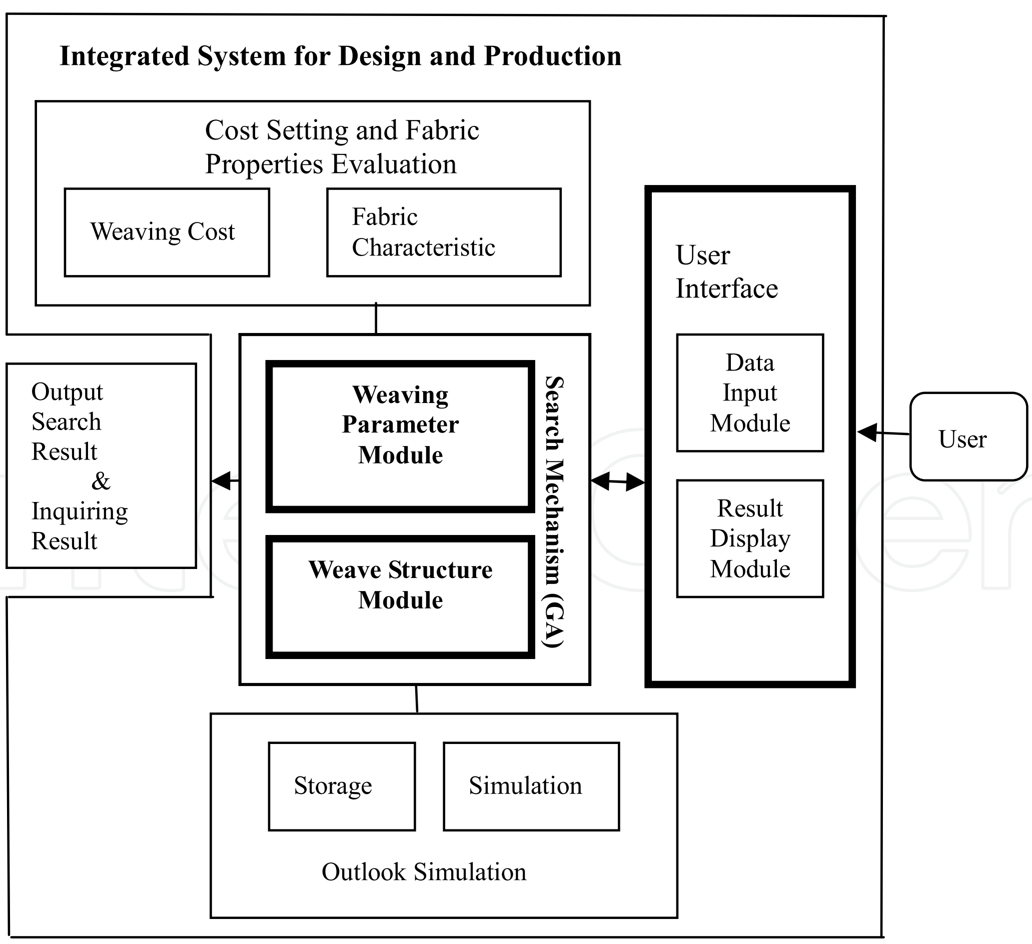


Fig. 1. Scheme of integrated system

2.1 Search mechanism

There are two search mechanisms included in the system; one is developed for the search of weave structure pattern, the other is for that of weaving parameters. The search mechanism is based on genetic algorithm (GA), which is an optimization technique inspired by biological evolution (Karr, 1999). Base on the natural evolution concept, GA is computationally simple and powerful in its search for improvement and is able to rapidly converge by continuously identifying solutions that are globally optimal with a large search space. By using the random selection mechanism, the GA has been proven to be theoretically robust and empirically applicable for search in complex space.

2.2 User interface

The user interface allows the user to set the basic parameters, e.g., population size, crossover rate, mutation rate, and the number of maximum generations, for GA to run. Besides, the user interface is of a function to display the searched results of the weave structure and the weaving parameters, on the monitor for the user to refer.

3. Search module for weaving parameters

3.1 Weaving parameters in production

Recent application of computer technology in the textile field (Inui et al., 1994) (Liu et al., 1995) (Ohra et al., 1994) (Hu, 2009) (Zhang et al., 2010) (Penava et al.,2009) , e.g., simulation systems for color matching, computer aided design (CAD) systems for static and dynamic states, and semantic color-generating systems for garment design. In this study, we propose an intelligent searching system theory based on a genetic algorithm to search for weaving parameters. There are five weaving parameters, i.e., warp yarn count, weft yarn count, warp yarn density, weft yarn density, and total yarn weight, which are all correlated to one another in weaving. If two or more than two parameters are unknown among them, there will be many available combinations.

Let's suppose there is a weaving mill that develops a fabric whose total weight consumption is preset as 5.6×10^{-7} (lb) per square inch. For simplification, the shrinkage of the fabric during weaving is neglected. There exist many combinations of weaving parameters (i.e., both yarn count and weaving density of the warp and weft), that can be used for preset weight consumptions of the material yarns. For instance, samples A, B, and C, shown in Table 1, all answer these demands. The areas of these three fabric pieces are similar- 1 square inch- but they have different yarn counts and weaving densities. Now the question is how a designer can easily and immediately obtain a lot of available combination sets of these four weaving parameters. In other words, it's difficult for a designer to acquire all the possible combination sets of weaving parameters simply through common sense. In addition, in order to speed up the production rate, the weft yarn count used in weaving is usually smaller than the warp yarn count. Thus the weaving density of the warp yarns is usually larger than that of weft yarns during implementation. Sample D's weaving density of warp yarn is smaller than that of its weft yarn. Sample E's warp yarn count is smaller than its weft yarn count. Sample F's weaving density of warp yarn is smaller than its weft yarn, and its warp yarn count is smaller than its weft yarn count. Therefore, Samples D-F shown in Table 1 are not available for practical use in weaving engineering.

Samples		N_1, 840yd/lb		N_2, 840yd/lb	n_1, ends/in		n_2, ends/in	W, lb	Size, Width × length
✓	A	1771.6	$N_1 \geq N_2$	885.8	10	$n_1 \geq n_2$	10	5.6×10^{-7}	1 in × 1 in
✓	B	1328.8	$N_1 \geq N_2$	1063.0	10	$n_1 \geq n_2$	10	5.6×10^{-7}	1 in × 1 in
✓	C	664.4	$N_1 \geq N_2$	531.5	5	$n_1 \geq n_2$	5	5.6×10^{-7}	1 in × 1 in
×	D	885.8	$N_1 \geq N_2$	885.8	5	$n_1 < n_2$	10	5.6×10^{-7}	1 in × 1 in
×	E	664.4	$N_1 < N_2$	5315.0	10	$n_1 \geq n_2$	10	5.6×10^{-7}	1 in × 1 in
×	F	664.4	$N_1 < N_2$	1063.0	5	$n_1 < n_2$	10	5.6×10^{-7}	1 in × 1 in

a ✓ available for practical application, × unavailable for practical application, N_1, N_2 yarn count of warp and weft yarns, respectively, n_1, n_2 weaving density of warp and weft yarns, respectively, and W total weight of woven fabrics.

Table 1. Combination sets of weaving parameters for samples A-F.[a] (Lin, 2003)

3.2 Genetic operators

A genetic algorithm (GA) (Gen et al., 1997) (Goldberg, 1989) (Karr et al., 1999) is a search method based on the mechanism of genetic inheritance. A genetic algorithm maintains a set of trial solutions, called a population, and operates in cycles called generations. Each individual in the population is called a chromosome, representing a solution to the problem at hand. A chromosome is a string of symbols, usually, but not necessarily, a binary bit string.

We adopted a search method, genetic algorithm (GA), to the combination sets. A genetic algorithm maintains a set of trial solutions, called a population, and operates in cycles called generations. Each individual in the population is called a chromosome, representing a solution to the problem at hand. A chromosome is a string of symbols, usually, but not necessarily, a binary bit string.

During each generation, three steps are executed.

Step 1. Each member of the population is evaluated and assigned a fitness value which serves to provide a ranking of the member.
Step 2. Some members are selected for reproductions.
Step 3. New trial solutions are generated by applying the recombination operators to those members which construct the new population after reproduction.

The genetic algorithm is shown in Figure 2 and a brief discussion on the three basic operators of GA is made as below.

a. Crossover
Crossover is the main genetic operator. It operates on two chromosomes at a time and generates offspring by combining both chromosomes' features. A simple way to achieve crossover would be to choose a random cut-point and generate the offspring by combing the segment of one parent to the left of the cut-point with the segment of the other parent to the right of the cut-point. This method of genetic algorithms depends to a great extend on the performance of the crossover operator used.
b. Mutation
Mutation is a background operator, which produces spontaneous random changes in various chromosomes. A simple way to achieve mutation would be to alter one or more

genes. In genetic algorithms, mutation serves the crucial role of preventing system from being struck to the local optimum.

c. Reproduction
Each set is evaluated by a certain evaluation function. According to the value of evaluation function, the number which survives into the next generation is decided for each set of strings. The system then generates sets of strings for the next generation.

3.3 Chromosome representation

A main difference between genetic algorithms and more traditional optimization search algorithms is that genetic algorithms work with a coding of the parameter set and not the parameters themselves. Thus, before any type of genetic search can be performed, a coding scheme must be determined to represent the parameters in the problem in hand. In finding solutions, consisting of proper combination of the four weaving parameters, i.e., warp yarn count (N_1), weft yarn count (N_2), weaving density of warp yarn (n_1), and weaving density of weft yarn (n_2), a coding scheme for three parameters must be determined and considered in advance. A multi-parameter coding, consisting of four sub-strings, is required to code each of the four variables into a single string. In a direct problem representation, the transportation variables themselves are used as a chromosome. A list of warp yarn count/weft yarn count/weaving density of warp yarn/weaving density of weft yarn was used as chromosome representation. The structure of a chromosome is illustrated in Table 2.

Parameter	Gene (bits)	Order	Layout of Chromosome
Warp count (N_1)	4	1~4	16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Weft count (N_2)	4	5~8	4 bits n_2 / 4 bits n_1 / 4 bits N_2 / 4 bits N_1
Warp Density(n_1)	4	9~12	
Warp Density(n_2)	4	13~16	

Table 2. Structure of a chromosome (Lin, 2003)

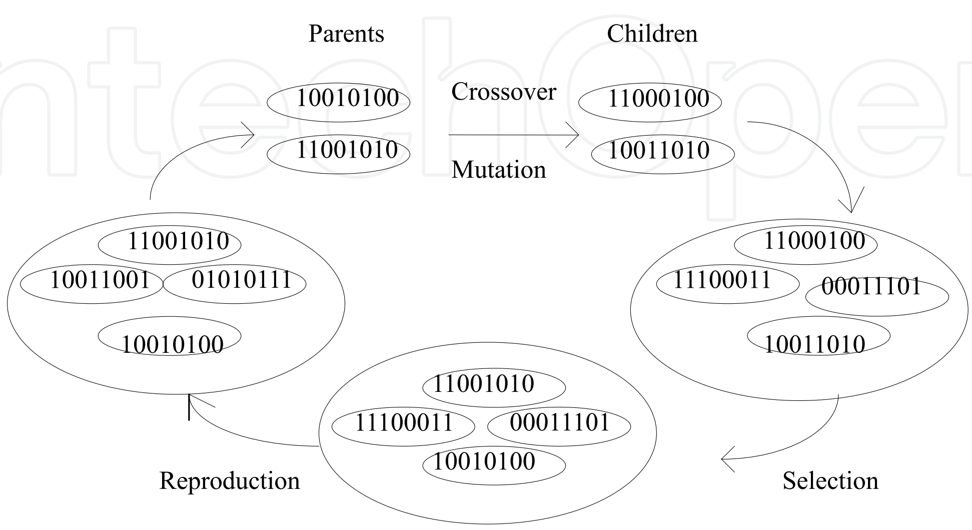


Fig. 2. Flow chart of genetic algorithm

3.4 Encoding and decoding of chromosome

The domain of variable x_i is $[p_i,q_i]$ and the required precision is dependent on the size of encoded-bit. The precision requirement implies that the range of domain of each variable should be divided into at least $(q_i-p_i)/(2^n-1)$ size ranges. The required bits (denoted with n) for a variable is calculated as follows and the mapping from a binary string to a real number for variable x_i is straight forward and completed as follows.

$$x_i=p_i+k_i(q_i-p_i)/(2^n-1) \quad (1)$$

where k_i is an integer between 0~2n and is called a searching index.

After finding an appropriate k_i to put into Equation 1 to have a x_i, which can make fitness function to come out with a fitness value approaching to '1', the desired parameters can thus be obtained.

Combine all of the parameters as a string to be an index vector, i.e. $X=(x_1,x_2,....,x_m)$, and unite all of the encoder of each searching index as a bit string to construct a chromosome shown as below.

$$P=b_{11}...b_{1j}b_{21}...b_{2j}........b_{i1}...b_{ij} \qquad b_{ij}\in \{0,1\}\ ;\ i=1,2,...,m;\ j=1,2,...,n; \quad (2)$$

Suppose that each x_i was encoded by n bits and there was m parameters then the length of Equation 2 should be a N-bit (N=m×n) string. During each generation, all the searching index k_{is} of the generated chromosome can be obtained by Equation 3.

$$k_i=b_{i1}*2^{n-1}+ b_{i2}*2^{n-2}+...+ b_{in}*2^{n-n} \qquad i=1,2,...,m; \quad (3)$$

Finally the real number for variable x_i can thus be obtained from Equations 1-3. The flow chart for the encoding and decoding of the parameter is illustrated in Figure 3.

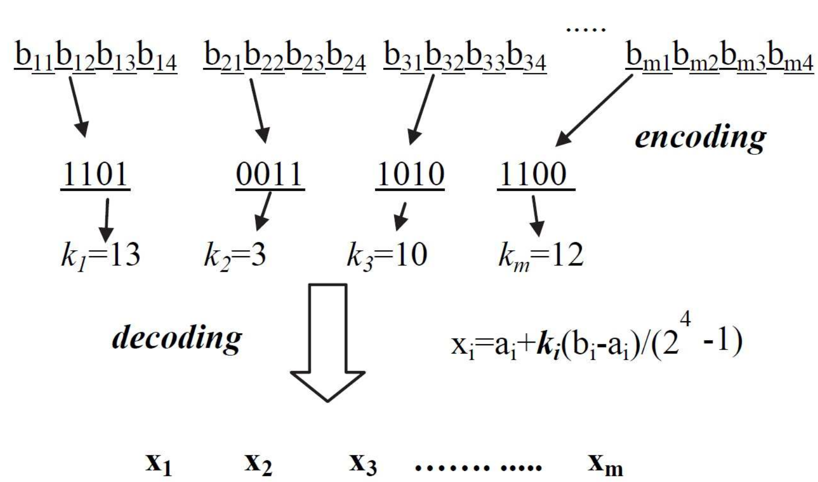


Fig. 3. Flow chart for encoding and decoding of the parameter with 4-bit precision

3.5 Object function

The fitness of the GA used in the system is shown in Equation 4. This approach will allow the GA to find the minimum difference between W and W_g when the fitness function value is maximized.

$$Fitness(W_g) = 1 - \frac{|W - W_g|}{W} \tag{4}$$

Where W_g (lb) is the decoded weight of the yarn for each generation, W(lb) is the target weight of the yarn and can be calculated by using Equation 5.

$$W(lb) = \frac{n_1 \times L \times Width}{(1 - S_1) \times N_1 \times 840} + \frac{n_2 \times L \times Width}{(1 - S_2) \times N_2 \times 840} \tag{5}$$

Where n_1 is the density of the warp (ends/inch), n_2 is the density of the weft (picks/inch); N_1 is the warp yarn count (840 yd/lb), N_2 is the weft yarn count (840 yd/lb), S_1 is the shrinkage of the warp yarn (%),S_2 is the shrinkage of the weft yarn (%), L (yd) is the length of the fabric, and Width (inches) is the width of the fabric.

3.6 Necessary to set constrained conditions

Generally speaking, while expecting to increase the production rate, a designer often leaves the weft yarn thicker than the warp yarn. Furthermore, the number of interlacing points will be different depending on the weave structure. There exists a maximum warp or weft weaving density for woven fabrics during weaving (Lin, 1993) (Pon, 1992). As a practical consideration, the weaving mill always adopts 90% of the maximum weaving density for warp and weft yarns to prevent jammed fabrics, which have a bad hand. In order to make the searching mechanism of the system more realistic and approvable, it is necessary to consider the constrained condition mentioned above. The conditions that essentially need to be considered during weaving can be illustrated as follows: (!)$n_1 \geq n_2$, (2) $N_1 \geq N_2$ (3) $n_1 \leq X \times 0.9$, (4) $n_2 \leq Y \times 0.9$, where X is the maximum weaving density of the warp yarn (end/inch), Y is the maximum weaving density of the weft yarn (picks/inch), n_1 is the density of the warp (ends/inch), n_2 is the density of the weft (picks/inch), N_1 is the warp yarn count (840 yd/lb), and N_2 is the weft yarn count (840 yd/lb). If the acquired chromosome's decoded part is not live up to the above-mentioned constrained conditions, it is essential for the system to set the fitness value at zero. Thus, the goal of preventing the system from deriving unfit solutions for the designer during the search is achieved.

3.7 Example

Table 3 is a set of conditions for a manufacture of fabrics. Table 4 is the results of the tenth generation searched by using GA. With the assistance of this system, many solution sets, consisting of weaving parameters (e.g., N_1,N_2,n_1,n_2), are obtained in a short time to help the designer make a decision more easily when exploring innovative fabrics. Moreover, the system will figure out the fractional cover (i.e., C) (Lin, 2003) of each solution set depending on the combination of weaving parameters generated after the interactive operation of the GA. For instance, the example shown in Table 3, has a GA whose operation conditions of crossover probability, mutation probability, and initial population are set to 0.6, 0.033, and 30, respectively. The decoded value of the ninth chromosome (i.e., 0100010010010100) from right to left per four bits is 30.7 (=N_1, 0100), 44.0 (N_2, 1001), 70.7 (=n_1, 0100), and 70.7 (=n_2, 0100), respectively. By putting these four decoded values into the calculation equation (Lin, 2003) of cover factor, a value of fractional cover can be obtained as 0.6394, yet it conflicts

Example	Known condition and set target			Constrained conditions
Searching for weaving parameters	Length(L)	constant	120 yds	(1)$n_1 \geq n_2$ (2)$N_1 \geq N_2$ (3)$n_1 \leq X*0.9$ (4)$n_2 \leq Y*0.9$ where X=a×b×a'/(b×b'+a×c) Y=b×a×b'/(a×a'+b×c') X,Y:maximum weaving density of warp and weft yarns a,b:maximum number of warp and weft yarn capable of being laid out per inch a',b': number of warp and weft yarns per unit weave structure c,c': number of interlacing point in warp and weft directions per unit weave structure
	Width(width)	constant	64 in	
	Shrinkage of warp yarn (S_1)	constant	6.3%	
	Shrinkage of weft yarn(S_2)	constant	6.3%	
	Warp yarn per inch(n_1)	variable	60-100 ends/in	
	Weft yarn per inch(n_2)	variable	60-100 picks/in	
	Count of warp yarn(N_1)	variable	20-60 Ne	
	Count of weft yarn(N_2)	Variable	20-60 Ne	
	Weight(W)	constant	58 lb	
	Weave structure	constant	plain 1/1	
	Material yarn (Warp/Weft)	constant	Cotton/cotton	

Table 3. Set target, known conditions, and constrained conditions (Lin, 2003)

with the constrained conditions mentioned above that N_1 (=30.7) be smaller than N_2 (=44.0). Thus, the fitness of this solution is set at zero. Among the thirty chromosomes illustrated in Table 4, a fabric manufacturer can easily choose several solution sets, whose fitness values are closer to 1 and are of appropriate fractional cover. Thus, the manufacturer can avoid designing a woven fabric that cannot be manufactured by the production division. Furthermore, a designer can achieve the goal of considering many essential design factors such as cost, functionality (e.g., hand, air permeability, and heat retaining properties, et al.), and the possibility of weaving during design stage.

4. Search module for weave structure

4.1 Weave structure in pattern design

Nowadays, the range of R&D cycle for textiles is much narrowed than ever before. Moreover, it is necessary for the enterprise to afford the demand of marketing change in small quantity and large variety for the commodity (Chen, 2005). Application of computer technology in the textile field is widely spreading. For instance, computers are used for the control of processing machine in the apparel production process. Grading or marking of the cutting machine is one of the successful applications of computer technology. The computer has enhanced a lot not only the functions of the hardware but the applications of software. However, most of its applications in textile industry focus on manufacturing processes and quality improvement (Ujevic et al.,2002), . Some of them are applied to the computer aided design (CAD) systems (Rodel, 2001) (Sano, 2001) (Inui, 2001) (Luo, 2005) (Cho, 2005). In the past, the traditional drawing tools and skills were used to transform designers' ideas into

Population	Chromosome	N_1	N_2	n_1	n_2	C	Fitness
1	0100010000011100	52.0	22.7	70.7	70.7	0.6946	0.7531
2	0100010000111001	44.0	28.0	70.7	70.7	0.6760	0.6948
3	0100010001011110	57.3	33.3	70.7	70.7	0.6247	0.5640
4	0100010100111001	44.0	28.0	73.3	70.7	0.6835	0.7050
5	0001010101101111	60.0	36.0	73.3	70.7	0.6165	0.5359
6	0100010101001110	57.3	30.7	73.3	70.7	0.6440	0.6029
7	0100010101011111	60.0	33.3	73.3	70.7	0.6275	0.5623
8	0001010100111011	49.3	28.0	73.3	62.7	0.6381	0.6266
9	0100010010010100	30.7	44.0	70.7	62.7	0.6394	0.0000
10	0100010000011100	52.0	22.7	70.7	70.7	0.6946	0.7531
11	0100010001111111	60.0	38.7	70.7	70.7	0.5995	0.5056
12	0001010101001110	57.3	30.7	73.3	62.7	0.6103	0.5590
13	0100110001111111	60.0	38.7	92.0	62.7	0.6314	0.0000
14	0100110001011110	57.3	33.3	92.0	70.7	0.6814	0.0000
15	0100011001101110	57.3	36.0	76.0	70.7	0.6283	0.5532
16	1101011001111111	60.0	38.7	76.0	94.7	0.7036	0.0000
17	0100010001010101	33.3	33.3	70.7	94.7	0.7667	0.0000
18	0100010000011111	60.0	22.7	70.7	70.7	0.6832	0.7226
19	0100010001011010	46.7	33.3	70.7	70.7	0.6451	0.6114
20	0100010000011110	57.3	22.7	70.7	70.7	0.6867	0.7319
21	0100110000011100	52.0	22.7	92.0	70.7	0.7442	0.0000
22	1101110001101110	57.3	36.0	92.0	94.7	0.7529	0.0000
23	0100010001111111	60.0	38.7	70.7	94.7	0.6924	0.0000
24	0100010000011110	57.3	22.7	70.7	70.7	0.6867	0.7319
25	0001011000011011	49.3	22.7	76.0	70.7	0.7117	0.0000
26	0001010100111100	52.0	28.0	73.3	62.7	0.6325	0.6138
27	0100010001111001	44.0	38.7	70.7	62.7	0.6035	0.5428
28	0100010100111111	60.0	28.0	73.3	70.7	0.6538	0.6302
29	0001010101001110	57.3	30.7	73.3	70.7	0.6440	0.6029
30	0100010001111111	60.0	38.7	70.7	70.7	0.5995	0.5056

Population:30, chromosome 16 bits, generation 10, crossover rate 0.6, mutation rate 0.033, N_1 840 yds/lb, N_2 840 yds/lb, n_1 ends/in, n_2 picks/in

Table 4. Result of the tenth generation (Lin, 2003)

concrete works. Due to the limitations above, a fabric design could not proceed more easily and effectively. Plenty of time was wasted on repeated paper drawing of the same types of different materials' colors and patterns. Besides, the different color combinations' outlooks of warp and weft yarn for a piece of fabric could only be obtained through a designer's imagination. Now, a simulation system (Ujevic, 2002) for color matching has already been put to practical use. The user of this system can confirm color matching of yarns by changing colors or patterns of weave structure displayed on the computer monitor of a computer with the system.

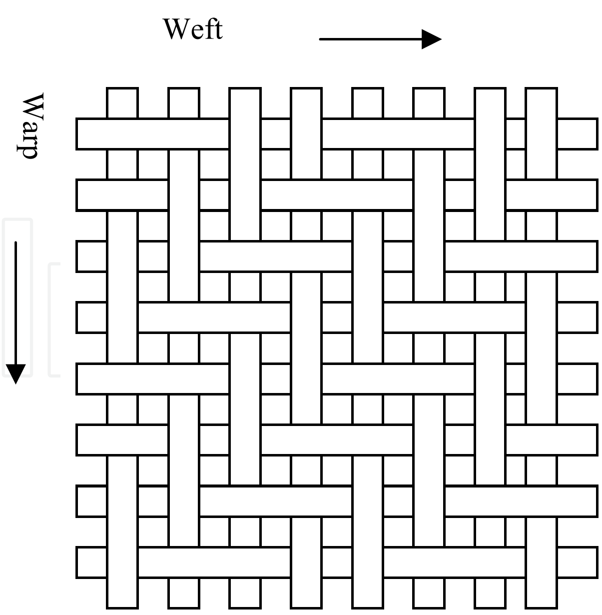
Therefore, the application of CAD to simulated woven-fabric appearance has been a major interesting research in recent years and various hardware and software systems are now available on the market for widely commercial applications (Denton et al., 1989) (Inui, 1994) (Pon, 1992). Until these systems became available, a considerable amount of time and money had been needed to show designers' ideas of fabric design in pattern (fabric sample) form. Probably only 15-20% of the patterns produced would have been approved for production by the sales department or the customers or both. Thus design can be a very expensive exercise for manufacturers engaged in the fancy woven fabric market. The introduction of CAD to textiles has provided a major breakthrough in multicolor weave design. With the help of CAD, designers can display, examine, and modify ideas very quickly on the color monitor before producing any real fabrics. Thus CAD allows a greater scope for free creative work on the part of designers without incurring a large cost increase. CAD allows a greater flexibility in the designer's work, and the designer's creativity is more effectively used.

However, the inspiration of a designer can do a weave structure designing, there is time for the designer to run out of his creativity for pattern design. Though the CAD is becoming more and more applicable to the pattern design, it has not yet become a complete tool to the textile designer because of limits to the function of color and material yarn selecting that can be created automatically. Up to the present, designers have got to be satisfied with a limited function of their own chosen color and material yarn recently available to display the simulation of the fabrics. Besides, due to the limits to the creative inspiration each designer has to face everyday, an intelligent design system is developed in this study to help a fabric designer with the creative weave structure design.

A piece of fabric is woven through the interlacing between the warp and weft yarn. The pattern of the woven fabric is illustrated through the layout of the different colors of the warp and weft yarn (Pon, 1992). The developed system can provide several appropriate combination sets of layout parameters that can meet the designer's satisfaction on the appearing pattern of the fabric without the need of advance lab manufacturing. With this system, a fabric designer can efficiently determine the warp (or weft) yarn color and weave structure to manufacture his satisfying fabric. Thus, the design and production division can be integrated. Furthermore, the running out of creative inspiration for a designer can thus be eliminated through the assistance of this developed system.

4.2 Encoding

Woven fabrics consist of warp and weft (filling) yarns, which are interlaced with one another according to the class of structure and the form of design desired (Hearle, 1969) (Shie, 1984) (Tsai, 1986). A concrete way of encoding textile weave is illustrated as Figure 4(B), whose weave structure is shown as. Figure 4(A). The unit of weaves was restricted to 8 by 8 for the sake of simplicity. The encoding value of '1' on the weave structure indicates 'warp float', the warp is above the weft and the encoding value of '0' indicates 'weft float', the warp is below the weft. The encoded result of a weave structure can be saved as a two-dimensional matrix and can be transformed into a bit string as a chromosome to proceed with crossover, mutation, and reproduction. After finishing the evolution, we can directly apply the obtained chromosome, i.e., bit string result ('1' denotes warp float, '0' denotes weft float) to plot the weave structure. The color of warp and weft yarn is encoded with 4 bits. There are totally 16 (= 24) kinds of color for each warp or weft yarn.



(A)

0	0	1	1	0	0	1	1
0	1	1	0	0	1	1	0
1	1	0	0	1	1	0	0
1	0	0	1	1	0	0	1
0	0	1	1	0	0	1	1
0	1	1	0	0	1	1	0
1	1	0	0	1	1	0	0
1	0	0	1	1	0	0	1

(B)

Fig. 4. (A) The schematic weave for the twill weave (B) The strings of the 8-harness twill weave

4.3 Chromosome

A main difference between genetic algorithms and more traditional optimization search algorithms is that genetic algorithms work with a coding of the parameter set and not the parameters themselves (Goldberg, 1989). Thus, before any type of genetic search can be performed, a coding scheme must be determined to represent the parameters in the problem in hand. In finding weave pattern solutions, consisting of proper combination of the three variables, including weave structure (i.e., the combination of warp float and weft float), warp yarn color, and weft yarn color. A multi-parameter coding, consisting of three sub-strings, is required to code each of the three variables into a single string. In this study, a binary coding is utilized and the bit-sizes of the encoding for the three variables are as follows. In a direct problem representation, the weave pattern variables themselves are used as a chromosome. A list of weave structure/warp color/weft color is used as chromosome representation, which represents the permutation of patterns associated with assigned weave structure, warp color and weft color. A gene is an ordered triple (weave structure, warp color, and weft color). This representation belongs to the direct way, which is sketched in Figure 5.

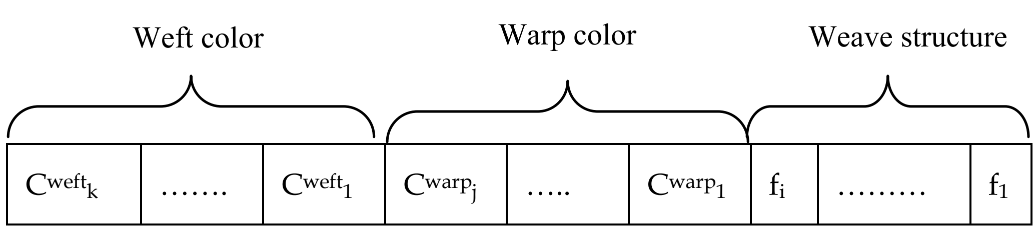


Fig. 5. Representation Scheme of Chromosome

4.4 Fitness function

In this study, the fitness function (i.e., evaluation function) is the user's preference. They are completely free for an operator to give a mark to the generated pattern without any restrictions depending on his/her being satisfied with it. GA is of an evolution capability based on the fitness value of each chromosome. The bigger the fitness of a chromosome is, the more probability it has to survive (be chosen). In other words, the gene (the feature) of the chromosome, which has bigger fitness than the others, will survive (be chosen) more easily to proceed with the operators, such as crossover, mutation, and reproduction, to create a brand new chromosome. Thus, the feature of the new generated chromosome will be inherited from the old chromosome composed of the required gene (i.e., feature). Moreover, each result of the generated chromosome for every generation can be reevaluated according to user's preference after examining the displayed pattern of weave structure decoded from generated parameters of W_S, C_{warp}, and C_{weft1}~C_{weft8}. By judging from the status of the displayed pattern, the user gives a mark (i.e., 0~1) to each of the pattern according to the satisfaction degree of each of them to the user. Thus, the fitness function is the user's preference and can be formed as Equation 6.

$$\text{Fitness}(\text{pattern}_i)=\text{User's preference}(\text{pattern}_i) \quad (6)$$

4.5 Example

In this study, we use this system to search pattern parameters afforded to the predetermined specifications set as in Table 5, i.e., unit weave structure: 8 ends × 8 picks, the layout of warp yarn color is adopted as one color for simplification (if necessary, it can be set as various colors), and that of weft yarn is adopted as various colors. The desired pattern style is something like being of both the features of regular grid and interlacing twist.

4.5.1 GA coding scheme and chromosome

A main difference between genetic algorithms and more traditional optimization search algorithms is that genetic algorithms work with a coding of the parameter set and not the parameters themselves. Thus, before any type of genetic search can be performed, a coding scheme must be determined to represent the parameters in the problem in hand. In finding solutions, consisting of proper combination of the three pattern parameters mentioned above, a coding scheme for three variables (i.e., the weave structure, warp yarn color, and weft yarn color) must be determined and considered in advance. A multi-parameter coding, consisting of three sub-strings, is required to code each of the three variables into a single string.

In this study, a binary coding (Gen et al., 1997) (Goldberg, 1989) is utilized and the bit size of encoding for the three variables, i.e., the warp and the weft yarn color were all set as 4 bits, and the weave structure were set according to the size. For instance, the bit size of a weave structure consisting of 8 ends × 8 picks is set as 64 bits. In spite of the same weave structure, the pattern of the fabrics can be various a lot due to the different layout of the yarn color. Therefore, the layout of the warp (or weft) yarn color is a crucial factor for the woven fabric design. The searched result for the pattern of weave fabric is various with the layout of the yarn's color. For simplification, the 16-color (4 bits) layout resolution is applied in this study.

Example	Known condition and set target			Constrained conditions
Searching for pattern parameters	(1) Unit weave structure		8 ends × 8 picks	(1)There is none of "1" successively in a column for an unit weave structure
	(2) Layout of color yarn	Warp	Same color	
		Weft	Different colors	
	(3) Desired pattern		The desired pattern style is of both the features of "regular grid" and "interlacing twist".	(2)There is none of "0" successively in a column for an unit weave structure (3) There is none of "1" successively in a row for an unit weave structure (4) There is none of "0" successively in a row for an unit weave structure

Table 5. Set target, known conditions, and constrained condition (Lin, 2008)

If necessary, it is available for the system to adopt more than 16 colors (4 bits) layout resolution. The coding and decoding methods for the color resolution are briefly discussed as follows. For instance, in case of the searching range of yarn's color ranges between 0 and 15 (i.e., 16 colors), 4 bits are needed for encoding. Thus Equation 1 can be reformed as follows.

$$\left.\begin{array}{ll} k=0 & x=0+0*(15-0)/15=0 \\ k=1 & x=0+1*(15-0)/15=1 \\ k=2 & x=0+2*(15-0)/15=2 \\ \multicolumn{2}{c}{\dots\dots\dots\dots\dots\dots\dots\dots\dots} \\ k=15 & x=0+15*(15-0)/15=15 \end{array}\right\} \tag{7}$$

The chromosome of weave pattern consists of 3 parts, i.e., (1) the gene of weave pattern (1~64 bits) (2) the gene of the layout of the color of warp yarn (65~68 bits) (3) the genes of layout of the color of weft yarn (69~100 bits). For simplification, colors for all the warp yarns are set as the same in this study, the bit size is set to 4 bits. On the other hand, the colors for all the weft yarn (i.e., 8 picks) were set various to one another. Therefore, the size of the first sub-bit-string, representing the weave structure, is 64 bits, that of the second sub-bit-string, representing the color of warp yarn, is 4 bits, and that of the third sub-bit-string, representing all the different weft yarn colors, is 32 bits (=8 picks × 4 bits). Therefore, a chromosome string consisting of 100 bits can be formed and its layout can be shown as Table 6. Besides, if necessary, it is available for the system to set the colors of the warps (8 ends) to be various to one another. In other words, the second sub-bit-string (i.e., the second gene), representing the colors of the warps can be increased as 32 bits (= 8 ends × 4 bits), and the number of bits for the chromosome is reformed as 128 bits as well.

4.5.2 Fitness function and solution search

GA is of an evolution capability based on the fitness value of each chromosome. The bigger the fitness is, the bigger probability to survive (be chosen) is. In other words, the gene (the

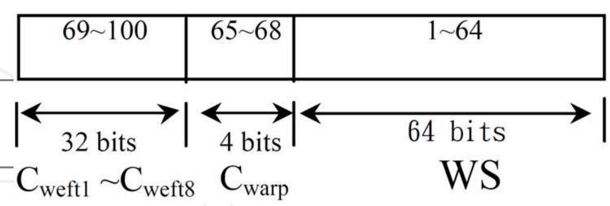
<table>
<tr><th colspan="2">Parameters</th><th>Gene size (bits)</th><th>Sequence of layout</th><th>Chromosome</th></tr>
<tr><td colspan="2">Weave structure (8warpx8weft) (WS)</td><td>1 bit× 64 float</td><td>1~64</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Layout of color yarns</td><td>Warp color (C_{warp}) 8 ends (same)</td><td>4 bits× 1 end</td><td>65~68</td></tr>
<tr><td>Weft color (C_{weft1}) 8 picks (different)</td><td>4 bits× 8 picks</td><td>69~100</td></tr>
</table>

Table 6. Layout of chromosome (Lin, 2008)

feature) of the chromosome, which has bigger fitness than the others, will survive (be chosen) more easily to proceed with the operators, such as crossover, mutation, and reproduction, to create a brand new chromosome. Thus, the feature of the new generated chromosome will be inherited from the old one composed of the required gene (i.e., feature). Moreover, each result for every generation can be reevaluated by examining the pattern display of weave structure decoded from generated parameters of W_S, C_{warp}, and C_{weft1}~C_{weft8}. By judging from the status of the displayed pattern, the user gives the mark to each of the pattern according to the satisfaction degree for each of them to him/her. In this study, the object function (i.e., fitness function) is the user's preference shown as Equation 6.

The simulation mechanism of the system can illustrate patterns on the monitor to help a designer give each a weighting value (i.e., fitness value). The user interface of the system is developed for helping a designer give each generated chromosome a specific weighting value (i.e., fitness value) ranging from '0' (denotes completely unsatisfied) to '1' (denotes completely satisfied) depending on the degree of his preference through comparing displayed pattern on the screen. Once each generated pattern is given a mark according to the user's preference, search mechanism of system can thus proceed with the operations such as crossover, mutation, and reproduction to produce the next generation.

Next the user can continue with the evolution of GA to search for the genuine design fabric pattern, with which he/she is satisfied. The user expects a satisfying pattern can finally be obtained. For an instance, eight weave structure patterns are illustrated on the monitor as shown in Figure 6A, the designer can give each of them a fitness value (i.e., weighting value of satisfaction) such as 0.8, 0.2, 0.8, 0.4, 1.0, 0.2, 0.4, and 0.6. After proceeding with several generations of evolution (rate of crossover: 0.6; probability of mutation: 0.033; Initial population:8), there comes up with a satisfying solution for this design case. Figure 6B shows the result of weave pattern after one generation. The designer can obtain a satisfying pattern among the obtained patterns listed on Figure 6B. In case none of them is satisfying, the designer can continue proceeding with the procedure illustrated as Figure 2 for another several generations till there is one can be obtained.

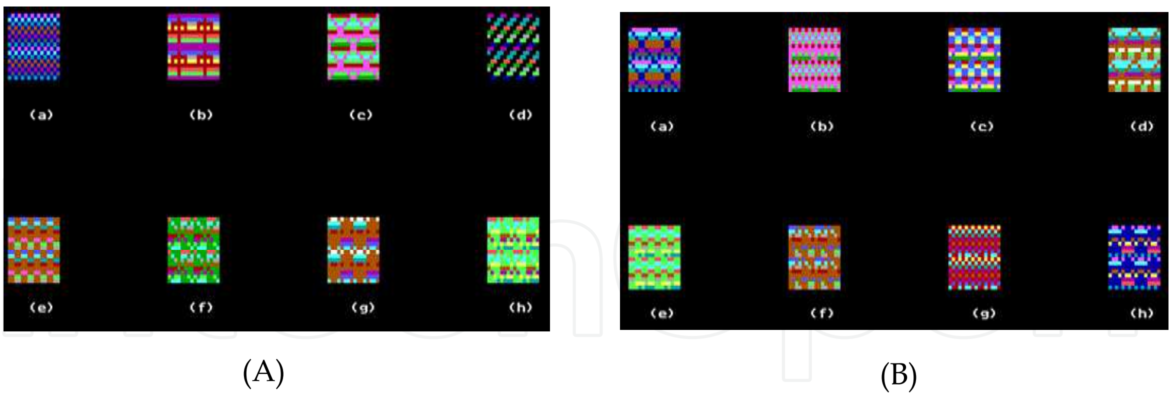


Fig. 6. (A) Weave pattern decoded from strings in the initial state,(a)~(h): denotes the 1st~8th population (B) Weave pattern after 1 generation of GA, (a)~(h): denotes the 1st~8th population

4.5.3 Necessity to set constrained conditions

Regarding the gene of the weave structure pattern (1~64 bits), one should check if the weave structure of 8 ends × 8 picks happens that there is complete warp or weft float in a unit weave structure (i.e., There are eight bits of "1" (or "0") successively in a column (or row) for a unit weave structure as shown in Figure 7.). If the above mentioned case does happen, the weft or warp yarn will not be fixed to the fabric's surface because none of crossing point. Thus, the genes (1~64 bits) of the chromosome should be set to "0" to avoid the bad evolution for the next other generations. Thus, the outcome gained after evolutions can be fit for the practical application.

4.5.4 Experiment results

With the assistance of this system, many solution sets, consisting of weave structure pattern parameters (e.g., W_S, C_{warp}, C_{weft1}~ C_{weft8}) are obtained in a short time to help the designer create a satisfying weave structure pattern more easily during exploring innovative fabrics. The example shown in Table 5, has a GA whose operation conditions of crossover probability, mutation probability, and initial population are set to 0.6, 0.033, and 8, respectively. The desired pattern style for the fabric is something like both the features of regular grid and interlacing twist.

Firstly, the system displays eight default patterns of weave structures on the monitor waiting for the user to give each of them a mark depending on his preference. Then the user can find out the monitor-displayed patterns closely similar to the feature of desired pattern such as Figure 6A(a), (c), (e), (h), which are of both the feature grid and interlacing twist pattern look. Judging from the eight patterns of weave structures illustrated on the monitor, the user can give each of them (i.e., a~h) a fitness value (i.e., weighting value of preference) such as 0.8, 0.2, 0.8, 0.4, 1.0, 0.2, 0.4, and 0.6 respectively.

Finally, the search mechanism proceeds with crossover, mutation, and reproduction to create new chromosomes (i.e., bits strings) fit for his demand. The first chromosome (i.e., Figure 6B (a)) of survey results after one generation is shown as in Table 7. In this instance, if the user is not yet satisfied with the searched result illustrated on the monitor, he/she can just proceed the next generation by giving each pattern another weighting value of preference to search for another combination of bit strings. He/She expects that there exists a chromosome with a much better pattern for his/her referring to during design stage by following the processing procedure: Start → Show eight patterns on the screen → Give each pattern a mark by user → System proceed with crossover, mutation, and reproduction → End.

The results of the first generation are shown in Table 7. The decoded value of the first chromosome (i.e., 0011100001010...10101), from right to left, the first 64 bits string (i.e., 10000…1010101), which can be reformed as a two dimensional matrix to represent the weave structure of fabrics, shown as the solution row in Table 7. The next 4 bits string (i.e., 0001), which denotes the color of the warp, is decoded as 1 (i.e., blue). The left 32 bits string (i.e., 0011100…11101), which can be decoded from right to left per four bits as 13 (=C_{weft1}=light Purple, 1101), 11 (=C_{weft2}=light Cyan, 1011), 3 (=C_{weft3}=Cyan, 0011), 6 (=C_{weft4}=Brown, 0110), 6 (=C_{weft5}=Brown, 0110), 5 (=C_{weft6}= Purple, 0101), 8 (=C_{weft7}=Gray, 1000), and 3 (=C_{weft8}=Cyan, 0011), respectively for each color of the eight picks of weft yarn. According to these obtained weave structure parameters (W_S, C_{warp}, and C_{weft1}~C_{weft8}), the simulation mechanism of the system can display the simulation image of the weave structure pattern, which is illustrated as in Figure 6B(a) with an expected look of the mixed feature of both grid and interlacing twist pattern.

Items	Pattern of weave structure																
Chromosome	0011100001010110011000111011110100011000000101000010001001000 0011000000110000010010001000010010101010																
Pattern parameters	Unit weave structure	Layout of yarn colors															
		Warp (the same)								Weft (the various)							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Solution	10000001←8th weft 01000010←7th weft 00100100←6th weft 00011000←5th weft 00011000←4th weft 00100100←3rd weft 01000010←2nd weft 01010101←1st weft ↑↑↑↑↑↑↑↑ 12345678 warp	0001	0001	0001	0001	0001	0001	0001	0001	1101	1011	0011	0110	0110	0101	1000	0011
		1	1	1	1	1	1	1	1	13	11	3	6	6	5	8	3

Table 7. Searched results of desired pattern

It is available for the simulation mechanism of the system to display the amplified simulation appearance of each the generated weave structure on the screen. With the assistance of the simulation mechanism, the designer can more precisely give the mark to each generated chromosome as a fitness value (i.e., weighting value of preference) depending on his own preference. Figure 7 is the pattern for the amplified weave structure of Figure 6B(a). There is none of complete warp (or weft) float in the horizontal or vertical direction of the weave structures as shown in Figure 6B. Thus, the practical use of these generated weave structures can be ensured. Furthermore, in case none of them is satisfied, the designer can still continue proceeding with the GA for another generation till there is a desired one can be obtained.

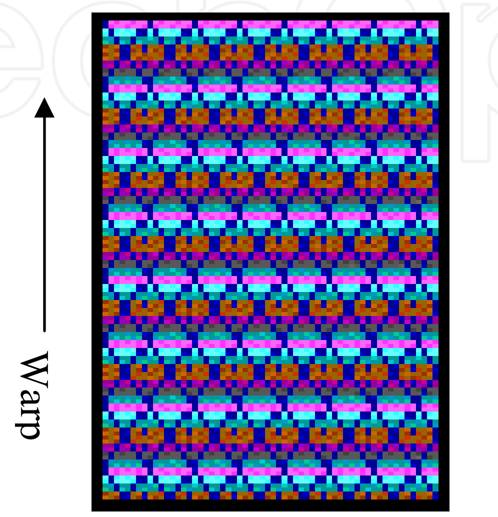


Fig. 7. Simulation pattern of the 1st chromosome for the first generation

5. Implementation of integration

At the very beginning, a consumer is usually attracted by the appearance of a fabric, which is related to the weave structure and the colors of the warp and weft yarns. Next, the characteristics, e.g., the permeability, the thickness, the tenacity, the elongation et al. of the fabric are required to be taken into consideration. Finally, the price of the fabric is used as an evaluation basis, by comparing which to the above-mentioned items (i.e., the outlook and the characteristics), the value of the fabric can thus be defined and determined.

Figure 8 illustrates the integration schemes of design and production for woven fabric. There are two search mechanisms included in the developed system, one is used to search for the weave structure, and the other is for the weaving parameters. The desired outlooks presented by the weave structure and the layout of color yarns can be generated and determined by using the weave structure module. The search for unknown combination of weaving parameters (i.e., N_1, N_2, n_1, and n_2) based on a preset cost consideration (i.e., total weight of material yarn) can proceed under both known width and length of a loom.

For instance, the outlook demand for weave structure pattern (i.e., a pattern style of regular grid and interlacing twist) is listed as shown in Table5 and that for production cost (i.e., fabric weight = 58 lb) is illustrated in Table 3. Firstly, in terms of designing a required

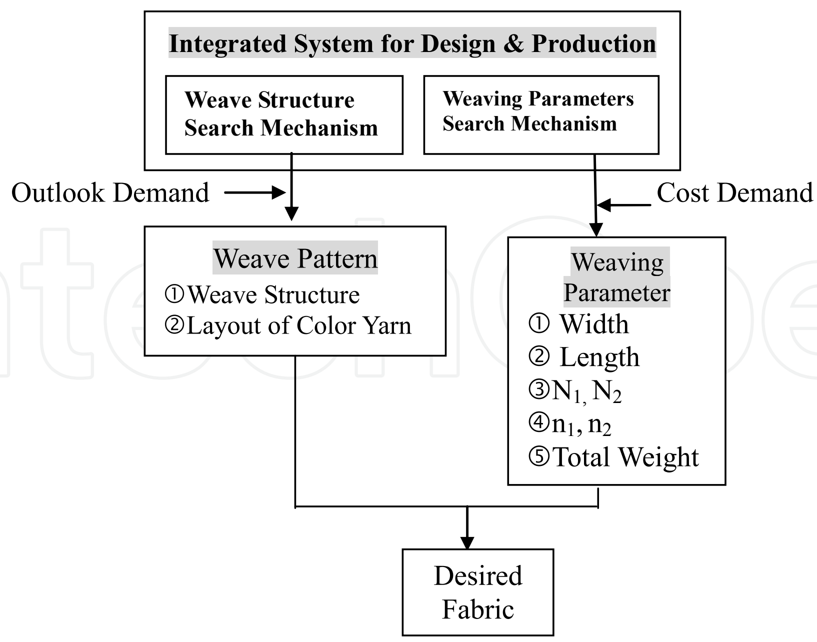


Fig. 8. Integration schemes of design and production for woven fabric

innovative weave structure, in order to obtain an integrated pattern of the appearance of above-mentioned characteristics, three basic patterns (as shown in Figure1a, 1c, and 1e) of the eight ones provided by the system, which are of some sorts of required characteristics and are more similar to the desired pattern, are given higher scores (i.e., fitness values) as 0.8, 0.8, and 1.0 respectively than the other five ones. After proceeding with several generations of evolution, there comes up with a satisfying solution as shown in Figure 6(B)a, the amplified of which is illustrated in Figure 7, for the desired pattern style. Secondly, as for finding a manufacturing solution to meet the cost demand (i.e., desired weight of 58 lb) of the fabric, the search mechanism for weaving parameters can help determine the combinations of weaving parameters (i.e., N_1, N_2, n_1, and n_2). The searched results of tenth generation are listed in Table 4, from which a designer can easily pick out the solution (i.e., N_1=52.0, N_2=22.7, n_1=70.7, n_2=70.7) of maximum fitness 0.7531, which can closely meet the weight demand of 58 lb while manufacturing. Through the assistance of this system, the design and production divisions can thus be integrated together.

6. Conclusions

In this study, an integrated system of design and production for woven fabric is proposed. There are two search mechanisms included in the integrated system. One is for the search of weaving parameters and is of an excellent search capacity to allow the fabric designer to obtain the best combinations of weaving parameters during manufacturing, considering costs. The other is for that of weave structure and can efficiently find appropriate combination sets of the pattern parameters, such as the weave structure (i.e., W_S), the layout of colors for warp yarns (i.e., C_{warp}), and that for weft yarns (i.e., C_{weft1}~C_{weft8}), during pattern design. A fabric designer can efficiently determine what the colors of the warp (weft) yarn and the weave structure should be adopted to manufacture satisfying fabric without the advance sample manufacturing. Both the time and cost consuming for sample manufacturing during design stage can be eliminated now. Moreover, the problem of running out of inspiration for a designer can be solved through the system's assistance as well. With the assistance of the developed integration system proposed in this study, the integration between design division and production one can be achieved. Thus, the competence of an enterprise can increase in the mean time.

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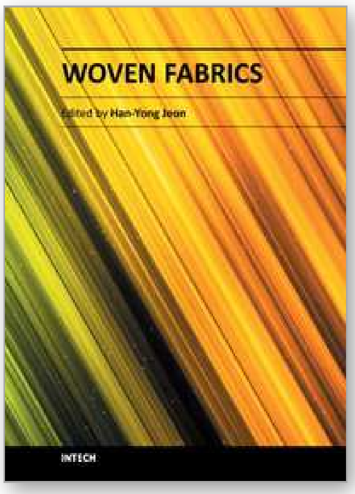

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"Woven Fabrics" is a unique book which covers topics from traditional to advanced fabrics widely used in IT, NT, BT, ET, ST industry fields. In general, woven fabrics are known as the traditional textile fabrics for apparel manufacturing and are used widely in various fabric compositions as intermediate goods that affect human activities. The relative importance of woven fabrics as traditional textile materials is extremely large and currently application fields of woven fabrics as technical textiles are rapidly expanded by utilizing its geometric features and advantages. For example, the book covers analytical approaches to fabric design, micro and nano technology needed to make woven fabrics, as well as the concept for industrial application.