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Development of Weave Code Technology for Textile Products

Abstract
The nature of the binary interlacing structure endows woven fabric with the ability of information coding. In this paper, we introduce the fundamental concepts and principles of weave code technology. Its potential applications in the fashion and apparel industry are also briefly described.

Key words: *weave code, fabric, watermark.*

Introduction

Weaving is the systematic interlacing of two sets of yarns (warp and weft) on a loom to form a piece of fabric. Every weave reveals a two-dimensional arrangement of warp and weft intersections, which can be represented mathematically by a binary matrix: 1- stands for warp on weft; 0 - stands for weft on warp and vice-versa. Weaving is an ancient technology to manufacture fabrics for the purpose of making cloth, with a history spanning thousands of years. With the development of materials, machinery and information technology, the functions of fabrics and garments are never limited to protecting the body from the weather or the requirement of aesthetic feeling: multi-functional garments have been developed with different purposes, such as to be bulletproof, fireproof, for health-care, wearable computing etc. However, the coding function of woven fabric has never been discovered nor adopted for the development of high-tech smart textile products.

In this paper, we first present the original concept of weave code technology, which could be defined as coding technology based on the binary structure of the woven structure, or weaving technology which can make codes wearable, flexible and fashionable. This technology could also be considered as a combination of weaving and coding technology, endowing fabric and garments with a coding function, which can be used directly in the designing, manufacturing, communicating and labeling of textile products. Our research on the fundamental concepts and principles of weave code technology might lead to a preliminary investigation of utilising fabric as a feasible platform or medium for the purpose of representing, encrypting, and communicating information.

Weave code technology involves typical interdisciplinary research integrating information science, textile technology and signal processing techniques, among which coding theory provides the basic mechanisms of information encoding and decoding. Textile technology concerns the designing and manufacturing of fabric, during which signal processing techniques, such as image analysis are selected to identify the internal weaving structure of fabrics. In this research, the basic principles and concepts of weave code technology as well as its potential applications are described accordingly.

Weave code technology

Fundamental concepts

The term "weaving coding" was first used by V. Milasius [3] in 1988 for the development of computer-aided textile design software; however, the meaning of "weave-coding" specified by the author is still the traditional one defined by textile science i.e. without the function of encoding and decoding.

As described in coding theory, it is conventional to represent information as being in one of two possible states [1]: a switch up or down, on or off, a hole punched or not, and so on. Each cross point of woven fabric could be considered as a binary element with two states: warp on weft and weft on warp, as illustrated in ***Figure 1***.

A set of parallel warp yarns are driven and controlled by a loom to form an open or closed shed sequentially for the filling of weft yarns through the shed, as shown in ***Figure 2***. Information in a binary format could represent the sequences of yarn interlacing along the warp and weft directions. For ease of mathematical description, a 2D matrix, whose elements are either 1 or 0, is used to record the data contained in the weave code, as depicted in ***Figure 3***. An additional column and row containing colour information of each yarn could be added to describe the colour weave code mathematically, as illustrated in ***Figure 4***. The use of colour in weave code technology could obviously increase the information density [5]; however, the accurate identification of yarn colour is required.

Assuming the weave code has dimensions *M*, *N*, measured in terms of yarn, then an information space of $2^{M\cdot N}$ patterns can be created without consideration of the yarn colour; in this case its information density will be

$$H=\frac{\log_2 2^{M\cdot N}}{M\cdot N}=1 \quad bit/cp$$

(*cp* - cross point). With respect to yarn colour (8-bit color), its information density could be increased to be

$$H=\frac{\log_2 2^{M\cdot N}\cdot 2^{8\cdot M}\cdot 2^{8\cdot N}}{M\cdot N}=1$$

$$=1+\frac{8}{N}+\frac{8}{M} \quad bit/cp .$$

When M & N are small, the information density could obviously be increased. Contrarily, the information density is increased slowly in the case of a large M and N due to the colour constraint in

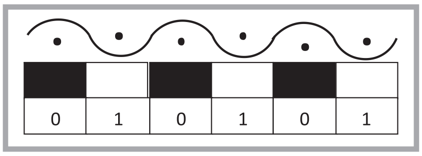


Figure 1. *Binary status of yarn interlacing (Vector format).*

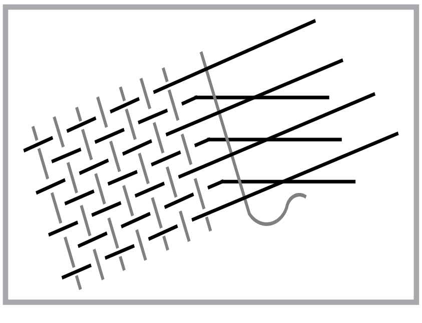
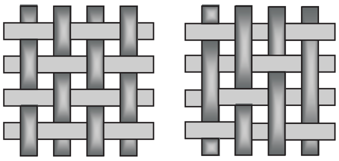
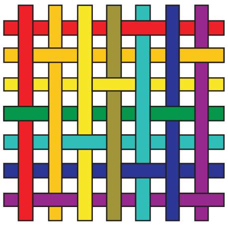


Figure 2. *Formation of a weave code.*



$$\begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \end{bmatrix} \quad \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

***Figure 3.** Mathematical description of a weave code (Matrix format).*



1	1	1	1	1	0	1	1
2	1	0	1	1	1	1	0
3	1	1	1	0	1	1	1
4	0	1	1	1	1	0	1
5	1	1	0	1	1	1	1
6	1	1	1	1	0	1	1
7	1	0	1	1	1	1	0
	1	2	3	4	5	6	7

***Figure 4.** Mathematical description of a weave code with colour (1-7 is the colour index); (Matrix format with colour index).*

one column or row. Given a square area of 1 cm × 1 cm with a yarn density of 50 yarns/cm, the capacity of this weave code is 2.5 KB, which is enough to record about 312 characters or a B/W logo with a size of 50 pixels × 50 pixels.

Essentially the yarn interlacing and weave code, presented in ***Figures 3*** & ***4*** in a binary format can be considered as different types of weave code farbic prototypes step by step: vector- > matrix- > matrix with a colour index. ***Figure 1*** focuses on the demonstration of the binary status of yarn interlacing, which is basis for developing weave code products. ***Figure 3*** is used to illustrate the corresponding relationship between the matrix and weave code, while ***Figure 4*** is used to illustrate how to add colour information into weave code products.

Basic Principles

Assuming an information source produces symbols of a finite alphabet $S = \{s_1, s_2, ..., s_k\}$, we can define a set of weave code units $W = \{w_1, w_2, ..., w_L\}$, where $L \geq k$ to make sure that each source symbol is represented by a weave code unit uniquely. The symbols could be given various interpretations: characters, pixel intensity, or audio signals according to the requirement of applications. The conversion of information into a sequence of codes is called "encoding". In this paper, we define a set of weave code units for characters: A - Z, a - z and 0 - 9, as illustrated in ***Table 1***, which is based on the ASCII character set. On the basis of the weave code format defined in ***Figures 1 - 4, Table 1*** is used to establish a lookup table between the text information and weave code, so that the text information can be embedded into weave code products.

Let $X = [x_1, x_2, x_3, ..., x_8]$,

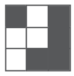
$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix},$$

X - ASCII be of one character, and
x_i - the i-th bit of X,

W being the weave code unit of this character, then

$$W = \begin{bmatrix} x_1 & x_2 & x_3 \\ x_4 & x_5 & x_6 \\ x_7 & x_8 & 0 \end{bmatrix}.$$

***Table 1.** Weave code set for characters.*

Character	ASCII	Weave code elements
A	0100 0001	
...		
Z	0101 1010	
1	0011 0001	

The set of code words could be extended to represent other symbols with a maximum number of 29 = 512 units.

Given a plain text "weave code", a weave code matrix W_L could be generated with a simple combination of each weave code unit corresponding to its related character.

$$W_L = [w_w\ w_e\ w_a\ w_v\ w_e\ w_c\ w_o\ w_d\ w_e]$$

For ease of formatting, a square weave code matrix W_S could be generated as below:

$$W_S = \begin{bmatrix} w_w & w_e & w_a \\ w_v & w_e & w_c \\ w_o & w_d & w_e \end{bmatrix}$$

Where L is the number of characters, S - the row or column number of the square weave code matrix, in which case $S = ceiling(\sqrt{L})$ $S^2 \geq L$ and the matrix elements $w_{i,j\ (j \times S + 1 > L)}$ are set as zero matrices. ***Figure 5*** depicts a weave design containing a plain text "weave code".

Once a weave code matrix has been generated, watermark algorithms could be adopted for the purpose of ownership verification and authentication during communication or product tracing. This function might benefit copyright protection or the development of wearable authentication.

Watermarks [6, 7] can have the form of LSB manipulations: hidden mark codes,

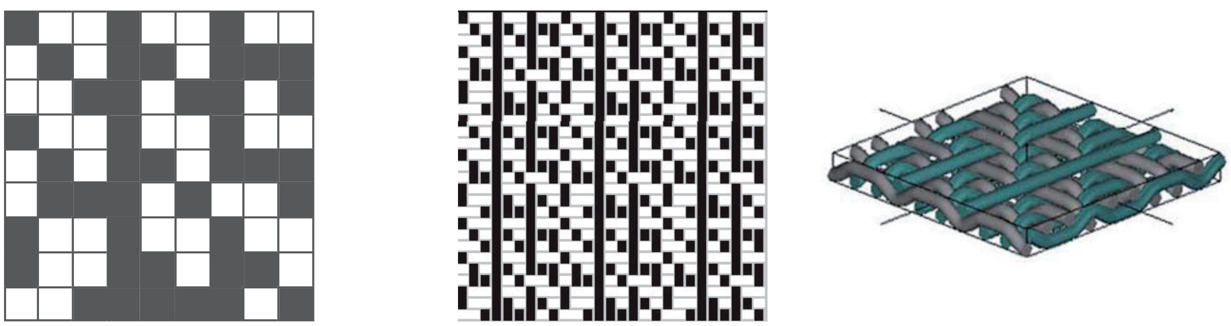


***Figure 5.** Weave design for the "weave code".*

invisible textures and secret constraints in transform domains, etc. depending on the nature of the signals. With respect to the weave code, we can define the watermark as a binary matrix

$$M = \{m(i,j); | m(i,j) \in \{0,1\}, i,j \in N\}$$

which can be a logo image or random pattern. Where W_0 denotes the original weave code before watermarking, W_m - the weave code after watermarking; ε and D are the embedding algorithms that cast a watermark M in the weave code W_0, and the detection algorithm separates the embedded watermark M and the original weave code W_0, $\varepsilon(W_0,M) = W_M$ and $D(W_M,M) = W_0$. Many references provide relevant research on the development of watermarking algorithms for binary imaging, which can be directly adopted in the development of weave code products. A detailed introduction of this will be described in following papers by the authors.

After information encoding and watermarking, weave code fabric could be manufactured on a jacquard machine, which is computer controlled with the ability of transferring the weave code design directly to a loom. Weave code products could be developed further on the basis of weave code fabric, such as weave code garments and labels etc.

As illustrated in ***Figure 6***, a scanning engine for weave code reading is quite important for the identification of weave code products; one specific scanning engine using an image analysis technique is utilised to scan and read the information embedded in weave code products. The identification of the weave code can be based on image analysis and pattern recognition [2]. The previous methods provide some effective prototypes and algorithms for the purpose of analysing a fabric interlacing structure at the yarn level; however, most of them only concern one-side surface image analysis, ignoring the dual-side nature of fabric, which could provide much more information for the purpose of accurate identification of yarn interlacing from one side to the other. A code scanner was designed in our research [8] together with a specific sample holder so that dual-side images of one fabric can be accurately digitalised and matched at the yarn level. The methodology for identification of a weave code is as follows: dual-side image scanning- > grid generation for the alignment of yarns- > dual-side image matching- > pattern recognition of each cross point- > generation of weave code. After reading the weave code embedded in textile products, watermark detection and decoding algorithms could be used to display information or watermarks contained in it. Since lots of relevant coding and decoding, or watermarking and detecting algorithms could be involved in this technology, more challenging and creative works are left for further development of this new technology.

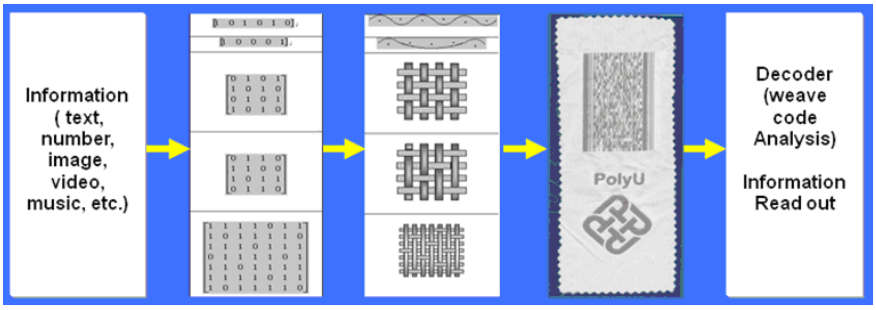


Figure 6. *Weave code design, manufacture and scan.*

The structure distortion of woven fabrics has effects on the appearane of weave code products, which should be considered in the actual development of weave code products. Two solutions are proposed here: one is to select suitable yarn and weaving technology to avoid it, and the other is to enhance the robustness of the scanning engine to identify the embedded information, even the existence of some distortions.

Comparison with Bar Code

The bar code [4] or matrix code [5], developed in the mid 1930s, is automatic identification (Auto ID) technology that streamlines product identification and data collection. A bar code is a graphic representation of data (alpha, numeric, or both) that is machine-readable. In terms of the coding function, a weave code is similar to a bar code; however, the implementation of these two coding technologies is different: A bar code is designed by using a combination of bars and spaces of varying widths, whereas a weave code is based on the interlacing network of warp and weft.

A bar code can be printed on a fabric surface or attached to garments as a tag or label. However, colour degradation or surface damage due to washing and wearing may lead to the failure of bar code scanning; the behaviour of throwing tags and labels away also causes information loss. In this case, a weave code has the obvious advantage of being embedded within the fabric structure; hence, information can be maintained throughout the useful life of textile products.

Potential applications

Weave code technology adds value to textile products – it is easier for fabrics encoded with more complete information to ensure their copyright or the brand protection of products, thereby preventing them from illegal duplication. With the product itself carrying more complete information, including material properties, this might provide a feasible cost-effective way of product tracking, as well as avoiding expensive testing and inspection processing. The weave code is a new innovative way of designing fabrics; that is, a simple plain weave can be updated to be a product with a high-tech look and feel, which could add design value through digital watermarking, pattern and texture generation. In the future, we believe that the potential use of the weave code in other product logistics and tracking is unlimited: from tagging and labeling authorised ribbon products, wearable ID's, to even weave coding a "soft disk".

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References

1. *Hamming R. W.; "Coding and Information Theory", 1992.*
2. *Kang T. J., Kim C. H., Oh K. W.; Tex. Res.J., Vol. 69, No. 2, 1999, pp. 77-83.*
3. *Milasius V., Reklaitis V.; J. Tex. Inst., 1988, pp. 598-605.*
4. *Pavlidis T., Swartz J., Wang Y. P.; Computer, Vol. 23, 1990, pp. 74-86.*
5. *Pavlidis T., Swartz J., Wang Y. P.; Computer, Vol. 24, 1992, pp. 18-28.*
6. *Voyatzis G., Pitas I.; Proceedings of IEEE, Vol. 87, July 1999, pp. 1197-1207.*
7. *Wu M., Tang E., Liu B.; "Data hiding in digital binary image," in IEEE Int. Conf. Multimedia & Expo (ICME'00), New York, 2000.*
8. *Xin B., Hu J., Baciu G., Yu X.; Tex. Res. J.; Vol. 79, No. 12, 2009, pp. 1123-1134.*

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