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DC Suppressed Fourier Power Spectrum Sum: A Means to Determine Periodicity (Repeat Unit) and Thread Count of Fabric Patterns

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Abstract— **Fourier spectrum has been a widely accepted approach by many researchers working in the area of analysis of fabric patterns and faults in the fabric. Due to more energy content in the Fourier power spectrum (FPS) as compared to Fourier spectrum (FS), the authors were motivated to use FPS to determine the periodicity of the woven fabric which has regular repeating units. The DC suppressed FPS sum was studied on simulated as well as real fabric patterns. The simulated fabric patterns studied have horizontal and vertical stripes, diagonal pattern, checks, plain and twill weave patterns which repeat regularly. These patterns are obtained either by using a program developed by us or by a commercially available Texcard software or from NET. The comparative study of FS, DC suppressed FPS without and with zero padding was carried out on simulated as well as real fabric patterns. The marginals obtained from DC suppressed FPS have shown the superiority in identifying the periodicity over the method using only FPS. Further observation on the first and second significant peaks of DC suppressed FPS sum plot in frequency domain along u and v direction have been found to act as very good measure of the periodicity or repeat unit (RU) and thread count in warp and weft direction of the pattern image. The accuracy of thread count is more than 99% respectively in both warp direction weft direction. It was also observed that the nature of power spectral view pattern identifies the fabric pattern. The details of the experimentation and the results thereof are presented in this paper.**

***Index Terms*—FFT, Marginals, Power spectrum sum, Periodicity (Repeat unit), Texcard software, Thread count.**

I. INTRODUCTION

The in-process quality control in any production unit is of vital importance. Though the emphasis in the past has been on visual inspections, the state-of-the-art technology using computer vision has given an edge to the automated inspection systems over manual inspections. The textile industries as on today also rely on such inspection systems. A lot of research has been carried out by many researchers using frequency domain approach to either characterize or classify the fabric pattern, or to find the fiber orientation or to find fabric structure [1],[2],[3],[4],[5]. Some researchers have used Fourier analysis method to detect the fabric faults [6] and some have used Fourier transform (FT) for crossed state detection in texture [7]. The characteristic of Fourier power spectrum (FPS) is to enhance the energy content of the FT. However, effort to use the sum of FPS with elimination of DC to study the fabric pattern and detect the fabric faults does not seem to be reported in the literature yet. This has motivated us to use this approach to establish the relationship between FPS and periodicity of fabric pattern. For real fabrics with fine count, the non-thread region decreases thereby increasing the DC component in the image and suppressing the frequencies of interest. This problem is alleviated by using DC suppressed FPS. The superiority of DC suppressed FPS over FS was also established through this research work to determine the periodicity and thread count of the gray fabric. Thread count is measured by counting the number of threads contained in one square inch of fabric, including both the length (warp) and width (weft) threads [10]. The details of the approach, its implementation and the results thereof are presented in this paper.

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II. FOURIER POWER SPECTRUM

Woven fabric consists of very minute repeat units that are periodic in nature. The repeat unit has definite number of ends and picks. The number of ends and picks may be equal or unequal [9]. Here the characteristic feature of Fourier transform to detect the periodic nature of any texture is utilized to obtain the Fourier spectrum and power spectrum of the simulated patterns and real fabric patterns. To understand and relate the power spectrums with fabric patterns, the Fast Fourier Transform (FFT) was first studied on the simulated patterns such as horizontal stripes, vertical stripes; diagonal stripes, plain and twill weave patterns. These are generated using both MATLAB program and Texcard software separately.

The Fourier transform (FT) is a representation of an image as a sum of complex exponentials of varying magnitudes, frequencies and phases. Features from power spectrum (PS) of a FT can be used to extract texture features [8]. FT of a 2-D spatial domain function $f(x,y)$ has real and imaginary parts and can be expressed as

$$F(u,v) = F_R(u,v) + jF_I(u,v) \tag{1}$$

Here u and v are the frequency variables in frequency domain corresponding to x and y of spatial domain. Fourier power spectrum, $P(u,v)$ is equal to the sum of the squares of the magnitudes of real and imaginary parts of FT and can also be obtained by multiplying $F(u,v)$ by its complex conjugate as,

$$P(u,v) = F(u,v)F^*(u,v) \tag{2}$$

and Since dynamic range of $P(u,v)$ is very large, it is a general practice to compute the log of FPS which retains zero values in frequency plane as,

$$\tilde{\tilde{P}}(u,v) = \log(1 + P(u,v)) \tag{3}$$

This is used only to visualize the power spectrum (PS) while it is calculated using (2). Since the power at the origin P (0,0) or FS at F(0,0) reflects the average brightness (DC) of the image, the peak frequency at origin (0,0) should be ignored while characterizing the texture [8]. The sum of the power transforms in u and v directions are computed from their corresponding marginals as,

$$P_u(u) = \sum_v P(u,v) \tag{4}$$

$$P_v(v) = \sum_u p(u,v) \tag{5}$$

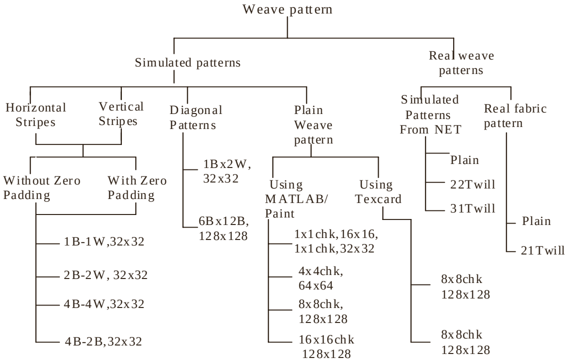
The peaks in these correspond to the presence of periodicity in the image. Pixels near the origin in the image represent low frequency terms that provide overall structure of the image [4]. In a weave, power spectrum peaks on the principal horizontal lines are associated with the warp yarns and those on the principal vertical line are associated with weft yarns.

III. PATTERNS UNDER STUDY

The Fourier transform and Fourier power spectrums were captured for various basic weave patterns [9] in a systematic way as shown below in a classification tree. Here, the image is given name x B – y W which means that the image has black stripe of width x pixels and white stripe of width y pixels. To investigate the repeat unit of real fabric, Motorized Micro- sterioscope was used as an imaging device with proper magnification and focus. The parameters were maintained throughout the study. Thirteen samples of real gray plain weave (Np1 to Np13) and sixteen samples of real twill weave (Nt1 to Nt16) were taken for this study.

A. Horizontal stripes

Fig.1.a to Fig.1.e depict the images of different weave patterns for simulated horizontal stripes of different stripe widths and sizes as indicated against each figure. Fig.1.f to Fig.1.j represent their Fourier spectrums. It is seen from the FS that, there are bright spots on y axis at x = 0. The distance between the centre spot F (0, 0) and the next bright spot on y-axis seem to give repeat unit (RU) of pattern. The distance



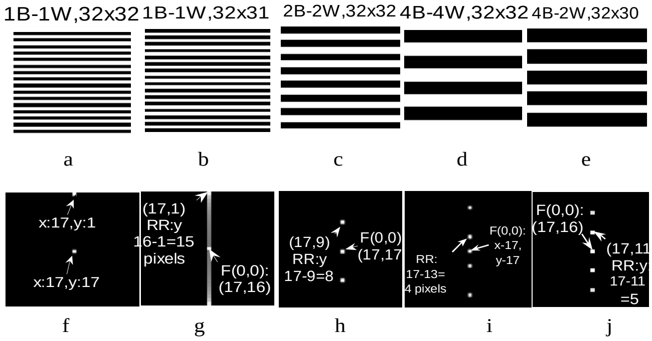


Fig. 1 :Images of Horizontal Stripes.
a to e : Horizontal Stripes of Different Widths,
f to j : Corresponding Fourier Spectrum Images.

of first bright spot in all was found to have relation to its respective RU. Comparative study of FS and FPS has been presented here considering various horizontal stripe patterns. For images in Fig.1, FS and FPS were obtained after zero padding which are as shown in Fig. 2.a to Fig. 2.e and Fig. 2.f to Fig. 2.j respectively.

1) *Observations for Horizontal Stripes.*

1. Referring to Fig. 1. f to Fig. 1.j for FS and Fig. 2.f to Fig. 2.j for FPS, it is seen that pattern in horizontal direction produces an intensity spot in vertical direction. This can be attributed to change in intensity that is along the vertical direction for such patterns.
2. By fine sampling (zero padding) the FT, the repeat unit spots in Fig 2.f to Fig 2.j were seen to be located at the same points as in Fig.2.a to Fig.2.e. However additional frequency details are seen in Fig 2.a to fig 2.e. Such details are absent in Fig.1. Additionally, the frequency component of interest corresponding to RU has been enhanced in FPS images compared to and FS images. Comparison of FS (Fig.1.f) and FPS spectrum (Fig. 2.f) for 1B-1W shows that the missing frequency component in FS is evident in zero padded Fourier power spectrum (ZPFPS).
3. As depicted in Fig. 1.f, h and Fig. 2.f, h, horizontal stripes with equal black and white stripe widths produce one pure frequency spot on Y-axis.
4. FS and FPS for Fig. 1.a, c and d indicate that broader horizontal stripes produce a frequency spot near to centre F (0, 0) along Y-axis. This confirms to lower repeat unit for broader stripes. Conversely for finer horizontal stripes frequency spots will be spaced away from the centre.

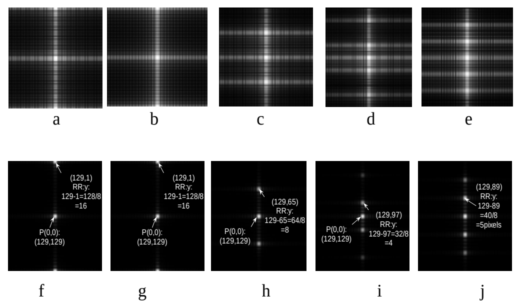


Fig. 2: Zero Padded Images of Fig.1
a to e: FS; f to j : FPS.

5. Pattern with unequal widths of black and white stripes as in Fig. 1.e produces pure frequency intensity spot that relates to repeat rate of stripes and high frequency spots (harmonics) along Y-axis which is attributed to narrow pulse effect.
6. It was also observed that FS and FPS plots are independent of the size of the image.

B. Vertical stripes.

The study of FS and FPS was repeated on simulated fabric with vertical stripes generated using the same method as that for horizontal stripes. All above mentioned points were observed in the FS and FPS except for the change in the axis i.e. along X-axis on which intensity spots were observed. Table I shows the results corresponding to various horizontal and vertical stripe patterns. Here Dx, Dy denote the distance of bright spot from centre P (0, 0) in x and y directions while RUy and RUx represent the periodicity along x and y direction respectively.

C. Diagonal Stripes

Since the other real weave patterns are twill patterns which are characterized by features along diagonal direction, two different diagonal patterns with size 32x32 pixels and 128x128 pixels were simulated for both FS and FPS as in Fig.3.a and b. It was observed that diagonal patterns produce an intensity spot along the normal to the diagonal direction of the pattern. Secondly the intensity spot in FS is very weak. However this gets enhanced in FPS. Table II shows the results corresponding to various diagonal stripe patterns.

D. Plain Weave Pattern

Plain weave produces simplest form of interlacing of threads in an alternate order. If the warp and weft threads are balanced in thickness and number per unit space, then a symmetrical uniform checks pattern is produced. Also this pattern is used in almost all kinds of cloths [8]. This motivated us to study the analysis of various such patterns. Simple Checks pattern as stated in classification chart was included for study.

Table I : Horizontal and Vertical stripe patterns

Stripe Image Details			Horizontalal stripes		Vertical stripes	
Sr. no	Type of stripes	Image Size In pixels	Dy	RUy	Dx	RUx
1.	1B-1W	32x32	16	16	16	16
2.	2B-2W	32x31	16	16	16	16
3.	2B-2W	32x32	8	8	8	8
4.	4B-4W	32x32	4	4	4	4
5.	4Bx2W	32x30	5	5	5	5

Table II : Diagonal Stripe Pattern

Sr.no	Diagonal pattern	Image Size In pixels	Distance of bright spot from P(0,0) on	
			x-axis	y-axis
1.	1/1	128x128	10	11
2	2/1	32x32	7	7

1) Checks pattern generated by program.

Sample Checks patterns namely 1x1 checks of size 16x16, 32x32 and 4x4 checks of size 128x128 are shown in Fig. 4.a, b and c. Since the studies of FS and FPS on patterns of simulated horizontal and vertical stripes have clearly indicated the superiority of FPS, only FPS study was carried out on these patterns. It is clear from Fig.4.d to f (i.e. FPS corresponding to Fig.4.a to c), bright spots are located at a distance of 1 unit for the first 2 checks while 4 units for the 3rd checks from the centre P (0, 0) in the diagonal direction.

For determining repeat unit or periodicity automatically, marginals from FPS can be computed using (4) for u direction and using (5) in v direction. This is assisted by study of location of peak frequencies. So FPS sum was computed and plotted for analysis. Fig. 5.a and b depict the FPS sum plot in u and v direction for checks of Fig.4.a and b. Also mesh plots of FPS in Fig.5.c and d indicate that the peak magnitude is higher for checks image of lager size. It is also observed that noisy checks introduce harmonics which are detectable in FPS sum plot.

Another Checks pattern generated by laying horizontal and vertical stripes at right angles, to mimic the huckbuck real fabric weave pattern as shown in Fig.6.a [9] was studied using Fourier Power spectrum with zero padding. Here bright frequency components corresponding to repeat units in horizontal, vertical as well as in diagonal direction are seen as in Fig.6.b and c. In order to cover a broad range of spectrum and also to catch any missing frequency components which may have significant contribution log of FPS was used. The pattern, FPS without ZP (PSWOZP) and with ZP (PSWZP) and Log (FS) are shown in Fig. 6.a – Fig. 6.d respectively. For these patterns, missing frequency components in FS (fig.6.b and f) are seen to be recovered in PS with ZP (Fig. 6.c and g) and also in Log (PSWZP) (Fig.6.d and h).

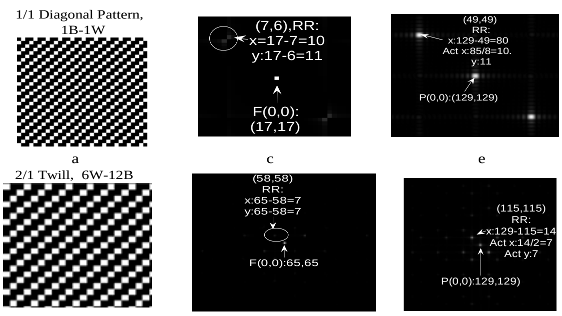


Fig. 3: a,b: Diagonal / Twill Pattern Images.
c,d: FS (without ZP); e and f: FS (with ZP).

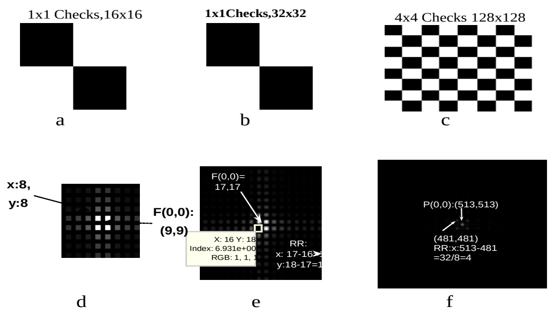


Fig.4.Checks Pattern of Different Sizes.
a, b:1x1; c:4x4;
d, e: PS for a, b; f : FPSWZP for c.

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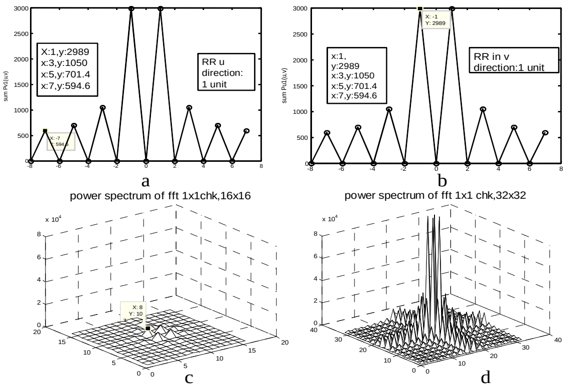

Fig.5. FPS Sum Plots for FPS of Fig. 4. a, b.
a: u Direction; b: v Direction,
c, d : PS Mesh Plot for Fig. 4.d and e.

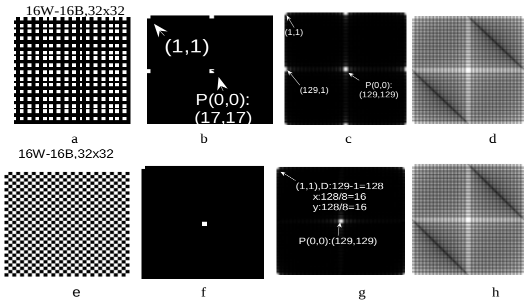

Fig. 6. Checks Pattern: a:Huckbuck Pattern; e:Checks ;
b, f : FS; c, g : PSWZP; d, h: Log (PSWZP).

2) Checks Pattern Generated by Texcard

Fig.7.a and b, c show an ideal pattern and simulated real pattern while Fig.7.d, e and f are their respective FPS. The bright spectrum spots on FPS are seen on both the diagonals as expected. Additionally the distances x and y of bright spots from the centre P (0, 0) are found to be equal to their repeat unit of checks pattern in u and v direction. Increase in RU of checks produces an intensity spot along the diagonal away from the centre. Table III shows results for these checks.

3) Observations on Plain Weave Pattern

1. Checks are equivalent to stripes in two directions, one in horizontal direction, while the other in vertical direction. So intensity spots corresponding to these are observed in both u and v directions and also in diagonal direction.
2. Power spectrum sum plot in u direction gives the repetition rate of checks pattern in y direction of the image and vice-a-versa.

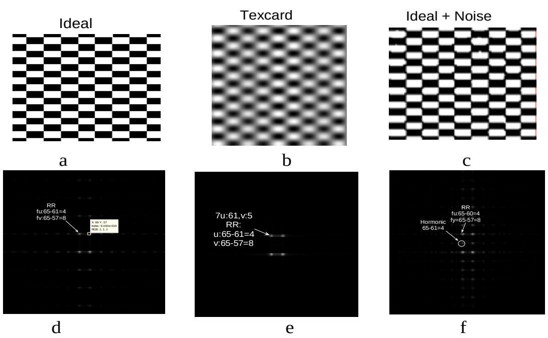

Fig. 7. Ideal & Texcard Generated 4x8 Checks Images.
a: Ideal Checks; b: Texcard Generated; c: Ideal with Noise;
d, e, f : FPS corresponding to a, b, c.

Table III: Checks Pattern				
Sr. No.	Checks Type	Image Size In pixels	x Distance of diagonal bright spot from P(0,0)	y Distance of diagonal bright spot from P(0,0)
1.	1x1	16x16	1	1
2.	1x1	32x32	1	1
3.	2x2	32x32	2	2
4.	4x4	128x128	4	4
5.	16x16	128x128	16	16
6	4x8	128x128	4	8

3. Horizontal distance of dominant frequency spot from the centre P (0, 0) in horizontal direction of power spectrum corresponds to repeat unit of checks in u direction (Fig. 7.d, e and f) similar to huckbuck weave pattern.
4. Vertical distance of bright frequency spot from the centre P (0,0) in vertical direction of power spectrum corresponds to repeat unit of checks in v direction.
5. Impure checks are found to produce additional intensity spots in power spectrum.
6. Log function helps to cover the entire dynamic range of frequency spectrum.

E. Real Plain Weave Pattern.

Above studies on simulated fabric pattern lead us to conclude that it is possible to find out the periodicity or repeat unit using FPS with zero padding and log scale. However above patterns deviate from the real fabric pattern at microscopic level. Hence the studies were carried out on the patterns of simulated real fabric images a) obtained from internet [10] which are near replica of the real fabric and b) the one captured by us.

Fig. 8.a and Fig. 8.b corresponds to simulated fabric and real fabric of plain weave pattern respectively. The FPS without zero padding and with zero padding for these images are also presented in Fig. 8.d to Fig. 8.f. FPS marginals for Fig.8. are shown in Fig.9. For FPS sum plots in u and v directions of Fig.9, the following notations are used for peaks obtained from marginals. The distances of the 1st and 2nd peaks in u/v direction from P(0,0) for FPS are denoted by Pu (u1,0)/ Pv (0,v1) and Pu (u2,0)/ Pv (0,v2) respectively.

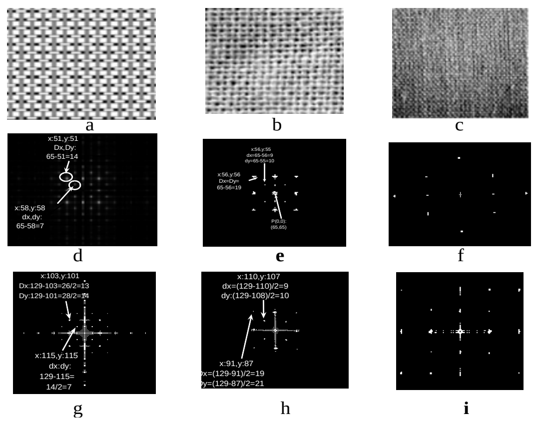

Fig. 8. Plain Fabric pattern.
a: Simulated, b: Real 128x128; c: Real 512x512 pixels;
d, e, f: PS Images without ZP;
g, h, i: PS Images with ZP and Thresholding for a, b, c.

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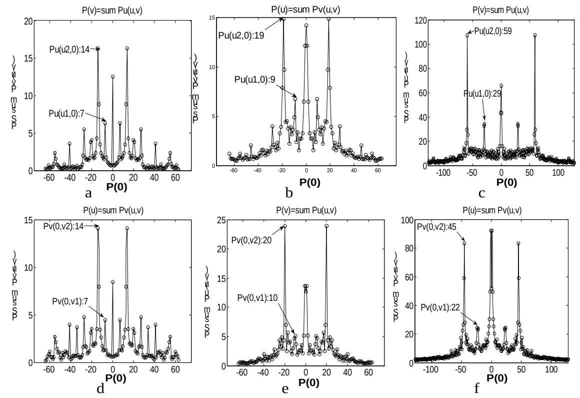

Fig.9. FPS Sum Plots.
a, b, c: Plot in u Direction; d, e, f: Plot in v Direction.

The nature of PS and FPS sum plots was found to be similar for simulated and real plain fabric pattern. The similar results of DC suppressed FPS sum plot obtained on two more real plain weaved fabric patterns with different magnification also confirmed to the actual ones. The results for these are given in Table IV. In all the cases distances of Pu (u1, 0) and Pu (u2, 0) from P (0, 0) were found to relate respectively to the repeat unit of pattern and number of threads in y direction of real plain pattern images. Similarly distance of Pv (0,v1) and Pv (0,v2) from P(0,0) respectively were found to relate to the repeat unit of pattern and number of threads in x direction of real plain pattern images.

1) Observations on simulated and plain weave pattern.

1. The FPS of Plain weave patterns is similar to check pattern with additional details. Bright intensity spots are present along both diagonal directions and along x and y direction.
2. Horizontal distance of dominant frequency spot from the center P (0, 0) of PS in u direction seems to relate to the repeat unit of plain weave in y direction.
3. Vertical distance of frequency spot from the centre P (0,0) of PS in v direction relate to the repeat unit of pattern in x direction. Refer Fig.8.d, e and f.
4. Image Power spectrum sum plot i.e. marginals in u and v direction relate respectively to the repeat unit of plain weave pattern in y and x direction of the image.

F. Twill weave pattern.

In twill weave pattern, the twill order of interlacing causes diagonal lines to be formed on both sides of cloth with the direction of lines may be to the right or left and the direction of lines on one side are opposite to that on the other side. Warp and weft on one side coincide with weft and warp on the other side [8]. The interlacing order is described by -2 up, -2 down or 2/2. Simulated twill patterns are obtained from Internet [10]. Fig.10 gives analysis of simulated 2/2 and 2/1 twill patterns and real 2/1 pattern. It is seen that the ZPPSs with thresholding exhibit their superiority over corresponding PSWOZPs. The 1st and the 2nd peaks of the marginal are again found to confirm to their repeat unit and number of threads in the x and y direction, thus confirming the earlier observation done for simulated plain weave pattern. The results are as tabulated in Table IV where symbol ‘S’ indicates simulated pattern.

Table IV: Real Simulated /Real fabric weave patterns

Weave Pattern		Image Size In pixels	Location of 1st peak=Repeat unit along		2nd Peak=No of Threads along	
			U	v	X	Y
PLAIN	Simulated	128x128	7	7	14	14
	Real	128x128	9	10	19	20
	Real	512x512	27	19	54	38
	Real Magnified	512x512	13	10	27	20
TWILL	2/2Twill (S)	128x128	4,15	4,14	15	14
	3/1Twill (S)	128x128	2,7	7	7	7
	2/1Twill Real	512x512	16	6	33	18

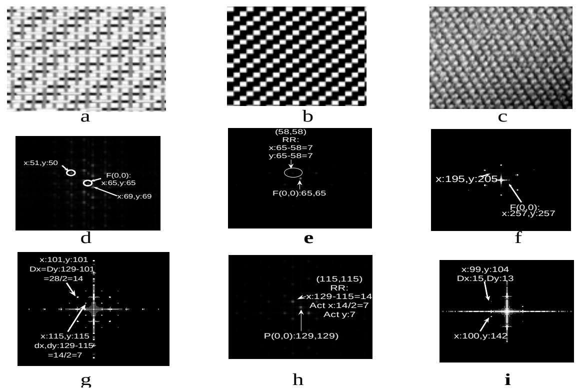

Fig.10. Twill Fabric pattern. a:2/2 Simulated, b:2/1 Simulated, c:2/1Real, d, e, f: PS Image without ZP; g, h, i: PS with ZP and Thresholding.

1) Observations on Simulated and real twill pattern.

1. Nature of Power spectrums and FPS sum plots of simulated and real twill images are found to be nearly similar.
2. PS sum plot in u and v direction give information that relates to the repeat unit and thread count of an image for pattern in y and x direction.
3. Distance of 1st peak frequency from the centre P(0) in u direction of PS sum plot corresponds to repeat unit of pattern and 2nd peak corresponds to the number of threads in the image in y (weft) direction of image for both simulated and real patterns.
4. Distance of 1st peak frequency from the centre P (0) in v direction of PS sum plot corresponds to repeat unit of

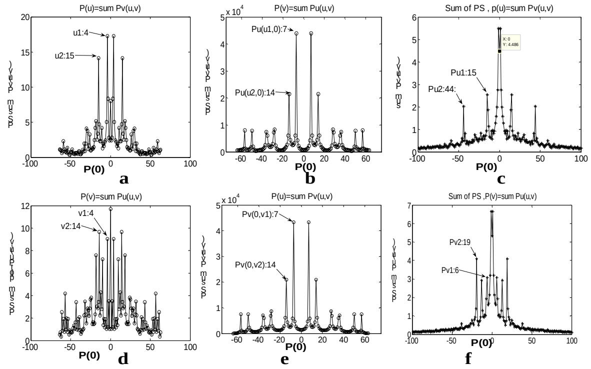

Fig. 11. FPS Sum Plot for Fig.10 a, b and c.
a, b and c: Plot in u Direction, b, c, d: Plot in v Direction.

pattern and 2nd peak corresponds to number of threads in x (warp) direction for both simulated and real twill patterns.

IV. RESULTS

DC suppressed sum of Power spectrum algorithm was applied on real normal plain and twill fabric samples. The specification of the plain fabric sample was 132x120 and twill fabric sample was 124x56. The length and width of the sample covered in the image were fixed and measured after standardization to find out the thread count per inch. Table V shows the results of repeat unit (periodicity) and thread count for plain weave samples Np1 to Np13 and Table VI depicts the thread count for different twill fabric samples from Nt1 to Nt16. The thread count obtained from our method has a maximum error of 0.95% for warp direction and 0.45% for weft direction.

V. CONCLUSION

In this paper we have presented a detailed analysis on repeat unit of different patterns such as horizontal stripes, vertical stripes, diagonal and plain weave (checks) patterns of different stripe widths and sizes using FS and FPS. It is seen that the FPS without DC depicts the enhancement of energy contents for various frequencies of interest and outweighs its superiority over FS. The change in the view pattern of FPS is observed for fabric patterns of different weaves. The FPS sum plot analysis on simulated and real normal fabric images of different weaves indicates that the 1st and 2nd strongest peak next to origin of FPS sum plot (marginals) can be used as good measure for finding the periodicity, as well as the number of threads in x (weft) and y (warp). Hence this method of analysis of the fabric images can be used as an in-process quality control check in fabric manufacturing. So we claim authentically that DC suppressed FPS helps in determining periodicity and thread count of all real fabric images of different weaves and patterns with very high accuracy.

Table V Real fabric : Plain weave patterns

Plain weave Sample No.	Location of peak along u direction		Location of peak along v direction	
	Pu1	Pu2	Pv1	Pv2
Np1	20	39	27	53
Np2	20	40	27	55
Np3	20	39	27	53
Np4	19	39	26	53
Np5	19	39	26	53
Np6	19	38	26	54
Np7	19	39	27	54
Np8	20	40	27	54
Np9	20	41	27	55
Np10	20	39	27	55
Np11	20	41	27	55
Np12	20	41	27	55
Np13	19	39	26	53
Average	19.61	39.53	26.69	53.88
Thread Count	Weft = 120.54		Warp = 132.05	
Accuracy	99.54%		99.45%	

Table VI Real fabric : Twill weave patterns

Twill weave Sample No.	Location of peak along u direction		Location of peak along v direction	
	Pu1	Pu2	Pv1	Pv2
Nt1	6	18	16	49
Nt2	7	19	17	51
Nt3	6	18	16	48
Nt4	6	18	16	49
Nt5	6	18	16	49
Nt6	6	18	16	50
Nt7	7	19	17	51
Nt8	7	19	16	50
Nt9	7	19	16	49
Nt10	6	18	16	49
Nt11	6	18	16	49
Nt12	6	18	16	48
Nt13	6	18	17	51
Nt14	6	18	17	51
Nt15	6	19	16	49
Nt16	6	18	16	51
Average	6.25	18.31	14.14	49.563
Thread Count	Weft = 55.83		Warp = 122.83	
Accuracy	99.69%		99.05%	

VI. FUTURE SCOPE

The Fourier Power Spectrum plot can be further used for studying and comparing the periodicity and thread count of the normal and faulty fabrics. If on-line optical inspection equipment is integrated with dedicated image processing software implementing above concepts for real time processing, either to warn the shop floor supervisor or suspend the process in the extreme case, then it will prove to be a great boon to the textile manufacturing industries.

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