Chapter 6

3D Fourier transform technique for the detection of defects in fabric improvised by optimized cylindrical filtering

6.1. Introduction

The spectral approaches such as the use of Fourier transform can well be applied for the detection of defects in fabric, especially for the fact that the uniform textured fabric image is composed of repetition of basic texture primitives with a deterministic rule of displacement. First systematic application of Fourier transform for pattern classification in woven fabric was proposed by Wood [65], who indicated that the Fourier power spectrum could be used for characterization. He also used filtering of power spectrum by using a computer generated mask for separating pile picture form the coloured pattern. Angular Fourier power spectrum was used for detection of changes in directionality, yarn density and yarn spacing in plain-weave cotton fabric [219]. Extensive computer application using fast Fourier transform (FFT) in identifying fabric structure was proposed in [220] to establish that spatial filtering technique could help in bringing out desired information for characterization of woven fabric. Automated visual detection and classification of defects in woven fabric based on two stage discrete Fourier transform was also performed under a window [221]. DFT was carried out as
four argument function \( f(u,v,m,n) \), instead of two argument function \( f(u,v) \), involving frequency indices \((u,v)\) and local image matrix \((m,n)\). Fourier transform analysis and the measurement of power spectrum for quality control in fabric was established [222, 223, 224, 225]. Specially designed detecting systems were used for such measurements on the diffraction pattern of the fabric for the detection of defects [226, 227, 228, 229].

However, in all the above spectral approaches, it is difficult to achieve expected performance for fabric samples which contains large stochastic variations [230]. The stochastic components usually appear from the in-homogeneity and hairiness of the fabric samples. Attempts are made to reduce the effects of these variations in fabric images by using perfectly contiguous and non-overlapping concentric rings of constant width which include various amounts of loosely localized frequency components in the 2D frequency plane.

Tsai & Kuo have proposed a 3D Fourier image reconstruction scheme to detect defects in in-homogeneously textured sputtered surfaces [226], where a sequence of faultless inhomogeneous 2D images and a 2D scene image under inspection are used to construct a new 3D image. Defect on inhomogeneous surfaces are then detected by observing the self-similarity pattern of 3D image from its frame-axis.

In this work, 2D fabric images of same fabric class containing different stochastic components and the 2D fabric image under inspection are taken along the frame axis for constructing the 3D fabric image. 2D fabric images along the frame axis create the self reference. This 3D fabric image is then 3D Fourier transformed. Fast defect detection of fabric sample is possible by considering a 3D band pass cylindrical filter having axis along the frame axis. In the reconstructed fabric image the defects are detected at a particular frame, from where finally the defective fabric portions are isolated by suitable energy threholding.

The selection of optimum value of radius of the 3D band pass cylindrical filter and energy threshold value are dependent on nature of fabric class and the fabric defect to be detected.
As these optimum values smooth the texture of fabric in normal region and well preserve the anomalies in the reconstructed fabric frame, suitable selection of these two parameters is the most important part for the success of the proposed method. In this chapter the optimum values of radius of band-pass filter and energy threshold value are obtained with the help of particle swarm optimization (PSO) technique.

6.2. Three dimensional Fourier transform and reconstruction method

As the stochastic and deterministic components are superimposed on each other in a fabric sample with defect, its detection becomes a complicated task. A solution of this complicacy is to compare the defective fabric sample with respect to healthy fabric samples of same fabric class. More is the number of reference healthy fabric samples better is the realization of the stochastic nature of fabric class. Therefore, it is required to process the concerned fabric images along with the reference healthy fabric images simultaneously. This simultaneous processing of multiple 2D fabric images can be done by constructing a 3D fabric image, which consists of the test fabric image and multiple number of healthy reference fabric images of same fabric class placed on a common frame axis, termed as fabric axis. The frame axis is perpendicular to the x-y axes (i.e z axis) if 2D fabric images are considered on the x-y plane. Such a 3D fabric image is shown in Figure 6.1.

![Figure 6.1: 3D fabric image](image_url)
The 3D Fourier transform method is now applied on this 3D fabric image. Let, 
\( f^q_z(x, y) \in \mathbb{R}^{(M \times N)} \) denotes a 2D gray scale fabric image at the fabric frame \( z \) of the 3D fabric image. Let this fabric image belongs to \( q \) th class of fabric, such that \( 1 \leq q \leq Q \) where total number of fabric class is \( Q \). If \( L \) numbers of such equal sized 2D gray scale fabric images of same fabric class are considered along the frame axis, then the entire 3D fabric image in space domain is represented as, 
\( f^q(x, y, z) \in \mathbb{R}^{(M \times N \times L)} \), where \( x \) varies from 0 to \( (M-1) \), \( y \) varies from 0 to \( (N-1) \) and \( z \) varies from 0 to \( (L-1) \).

This 3D gray scale fabric image in the space domain can be converted into the frequency domain by applying the 3D Fourier transform (3DFT) algorithm. The discrete Fourier transform of the 3D fabric image is defined as,

\[
F^q(u, v, w) = \sum_{z=0}^{L-1} \sum_{y=0}^{N-1} \sum_{x=0}^{M-1} f^q(x, y, z) \exp[-j2\pi \left( \frac{u \cdot x}{M} + \frac{v \cdot y}{N} + \frac{w \cdot z}{L} \right)]
\]

(6.1)

where, \( u = 0, 1, \ldots, (M-1) \), \( v = 0, 1, \ldots, (N-1) \), \( w = 0, 1, \ldots, (L-1) \) and \( F^q_w(u, v) \) denotes the 2D fabric image at \( w \) th output frame in the frequency domain.

3D FFT is simply the composition of a sequence of three sets of one dimensional DFTs performed along one dimension at a time (in any order). This compositional viewpoint immediately provides the simplest and most common derivation of multidimensional DFT by using the row-column algorithm [231] which is given as,

\[
F^q_1(x, y, w) = \sum_{z=0}^{L-1} f^q(x, y, z) \exp[-j2\pi \left( \frac{w \cdot z}{L} \right)]
\]

(6.2a)

\[
F^q_2(x, v, w) = \sum_{y=0}^{N-1} F^q_1(x, y, w) \exp[-j2\pi \left( \frac{v \cdot y}{N} \right)]
\]

(6.2b)
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\[ F^q(u,v,w) = \sum_{x=0}^{M-1} F^q_x(x,v,w) \exp[-j2\pi \left(\frac{ux}{M}\right)] \]  \hspace{1cm} (6.2c)

The energy of the Fourier transformed 3D fabric image at a particular fabric frame \( w \) can now be calculated as,

\[ E^q_w(u,v) = [R\{F^q(u,v,w)\}]^2 + [I\{F^q(u,v,w)\}]^2 \]  \hspace{1cm} (6.3)

where, \( R\{F^q(u,v,w)\} \) and \( I\{F^q(u,v,w)\} \) are the real and imaginary parts of \( F^q(u,v,w) \) respectively and \( E^q_w(u,v) \) is the energy of \( w \) th Fourier transformed fabric frame in frequency domain.

Evidently, the number of output frames in frequency domain is equal to the number of input frames considered in spatial domain. All the output frames in frequency domain contain information of all input frames i.e., all input fabric images. Different output frames in the frequency domain contain different amplitude of frequency components i.e., different energies.

The 3D fabric image, converted in the frequency domain can again be reconstructed back into the spatial domain by applying 3D inverse Fourier transform (3D IDFT) represented as,

\[ f^q(x,y,z) = [F^q(u,v,w)]^{-1} \]

\[ = \frac{1}{M.N.L} \sum_{w=0}^{L-1} \sum_{v=0}^{N-1} \sum_{u=0}^{M-1} F^q(u,v,w) \exp[j.2\pi \left(\frac{ux}{M} + \frac{vy}{N} + \frac{wz}{L}\right)] = [f^q_z (x,y)] \]  \hspace{1cm} (6.4)

The inverse Fourier transform method is also a composition of a sequence of three sets of one dimensional IDFTs performed along one dimension at a time (in any order). This computational viewpoint provides the following simplifications for the determination of 3D IDFT as,

\[ f^q_{1}(u,v,z) = \frac{1}{L} \sum_{w=0}^{L-1} F^q(u,v,w) \exp[j.2\pi \left(\frac{wz}{L}\right)] \]  \hspace{1cm} (6.5a)

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\[ f_2^q (u, v, z) = \frac{1}{N} \sum_{v=0}^{N-1} f_1^q (u, v, z) \exp [j.2\pi (\frac{v}{N})] \] (6.5b)

\[ f^q (x, y, z) = \frac{1}{M} \sum_{u=0}^{M-1} f_2^q (u, y, z) \exp [j.2\pi (\frac{u}{M})] \] (6.5c)

The reconstructed 3D fabric image also contains number of 2D fabric frames along the common frame axis. The number of fabric frames in the reconstructed 3D fabric image is equal to that of the input fabric frames. Taking the input fabric frames from same fabric class, such that the 2D fabric frames along the frame axis becomes the non overlapped fabric portions of the same fabric class, a faster detection of fabric defects is possible, as in this case the entire fabric image is processed simultaneously.

6.3. Removal of fabric background and detection of the fabric defect by 3D cylindrical filtering

The Fourier transform inherently presents signatures of the repetitive pattern i.e., interlaced grating structure of fabric in higher frequency bands along with unique local feature i.e., that of the defects in lower frequency bands of the Fourier spectrum. Thus, if the low pass filtering of the Fourier transformed fabric image is done by suppressing its dc component i.e., the central frequency, the defects are well preserved in the reconstructed fabric frame while its global feature i.e., the interlaced grating structure is suppressed. This is shown in Figure 6.2.

Figure 6.2(a), (b) and (c) show three synthetically generated fabric images with varying periodicity. Out of these fabric images, the fabric image in Figure 6.2(c) contains a defect. These fabric images are Fourier transformed individually. 2D band pass filter, suppressing the central frequency and having same outer radius for all of the above synthetic fabric images are operated on these individually. The reconstructed fabric images from the filtered
fabric images are shown in Figures 6.2(g) to (i), which correspond to Figures 6.2(a) to (c) respectively. The figures shown in Figures 6.2(g) to (i) do not contain the global i.e., background information, while in Figure 6.2(i) corresponding to Figure 6.2(c) contains the information of fabric defect.

Figure 6.2: (a) – (c) Synthetic fabric images, (d) – (f) frequency domain response of 2D Fourier transform of individual image before filtering, (g) – (i) reconstructed fabric images after 2D band pass filtering of images shown in (d) – (f) respectively with same inner and outer radii.

However, the main problem associated with the use of this 2D band pass filter is that the outer radius of the band pass filter may vary randomly for real fabric images, even belonging to same fabric class. This is because of the presence of stochastic component in the fabric
images. Moreover for different types of fabric defects taking place on fabric samples of same fabric class, the outer radius of 2D band pass filter may vary randomly. Thus it is necessary to design a band pass filter having an optimum outer radius which not only suppresses the global feature i.e., the background of the fabric image irrespective of the stochastic component it contains, but also preserve the local anomaly i.e., the defects. To implement this concept, the requirement is to design a 3D cylindrical band pass filter that operates simultaneously on all fabric frames in the frequency domain. This cylindrical band pass filter should suppress the global information in all filtered and reconstructed fabric frames irrespective of stochastic components it contain, while retaining the defective parts at the concerned filtered reconstructed fabric frames.

Therefore, a cylindrical filter with its major axis coinciding with fabric axis (i.e. z axis) is necessary. Such a 3D cylindrical band pass filter is taken along the frame axis, while its inner radius is constant in all cases as it suppresses only the central part, i.e., dc component of the Fourier transformed fabric image. The outer radius may be selected according the type of defect to be detected and also according to the type of fabric class. The schematic view of the 3D cylindrical filter is shown in Figure 6.3.

![Figure- 6.3: 3D cylindrical filter](image-url)
Mathematically, the 3D cylindrical band pass filter is represented as,

\[ F^{q}_{mod\,i}\mid_{w}(\frac{M}{2}, \frac{N}{2}) = 0 \]  \hspace{1cm} (6.6a)

and  \[ F^{q}_{mod\,i}\mid_{w}(u, v) = 0 \quad \text{for} \quad (u - \frac{M}{2})^2 + (v - \frac{N}{2})^2 > r^2, \forall w \] \hspace{1cm} (6.6b)

where, \( F^{q}_{mod\,i}\mid_{w}(u, v) \) is the \( w \) th output fabric frame in the frequency domain after the suitable 3D band pass filtering, \( r \) is the suitably selected outer radius of the cylindrical band pass filter.

3D output fabric image in the frequency domain after the suitable 3D band pass filtering is given by,

\[ F^{q}_{mod\,i}(u, v, w) = [F^{q}_{mod\,i}\mid_{w}(u, v)] \] \hspace{1cm} (6.7)

The filtered reconstructed fabric image in the spatial domain may be obtained as,

\[ f^{q}_{mod\,i}(x, y, z) = F^{q}_{mod\,i}(u, v, w)^{-1} = [f^{q}_{mod\,i}\mid_{z}(x, y)] \] \hspace{1cm} (6.8)

In fact the numbers of fabric frames along the frame axis is dependent on the stochastic component present in the fabric class. If the fabric class under consideration contains more stochastic components, more fabric frames have to be considered along the frame axis.

### 6.4. Isolation of defective fabric portion by suitable thresholding

The filtered reconstructed fabric frames may contain some insignificant diffused patterns. These patterns are not of our interest and hence considered as the noise. These noises are required to be removed for the proper detection of fabric defects at the suitably filtered reconstructed fabric frames. It has also been observed that the energies of the noise are less than the energies of the defective portion of fabric in the filtered reconstructed fabric frames.
Figures 6.4(a) and (b) show two synthetic fabric images taken as the input frames of the 3D fabric image. The 3D Fourier transform method is applied on this 3D fabric image. 3D band pass cylindrical filtering of the 3D Fourier transformed fabric image is done with suitable outer radius. The filtered reconstructed fabric frames are shown in Figure 6.4 (e) and (f) corresponding to Figures 6.4(a) and (b) respectively.

\[\text{Figure 6.4: (a) - (b): fabricated fabric images, (c) – (d): frequency domain response of 3D Fourier transform before filtering, (e) - (f): reconstructed fabric images after 3D cylindrical band pass filtering.}\]
From Figures 6.4(e) and (f) it may be observed that the energy of noise is small in comparison to that of the defective fabric portion in the filtered reconstructed fabric images. So a suitably selected energy threshold value is needed to extract the defective fabric portion, while suppressing their global information. The energy thresholding operation may mathematically be denoted as,

\[
\begin{align*}
\text{if } E_{\text{mod}i}^q |_z (x, y) > \theta & \quad ; f_B^q |_z (x, y) = 1 \\
\text{else } & \quad ; f_B^q |_z (x, y) = 0
\end{align*}
\]

(6.9)

where, \( E_{\text{mod}i}^q |_z (x, y) \) is the energy of \( z \) th filtered reconstructed fabric frame of the filtered reconstructed 3D fabric image \( f_{\text{mod}i}^q (x, y, z) \); \( \theta \) is the suitably selected energy threshold value and \( f_B^q |_z (x, y) \) is the binary image of the \( z \) th filtered reconstructed fabric frame after suitable energy thresholding.

### 6.5. Selection of values of radius of cylindrical filter and energy threshold by particle swarm optimization (PSO) method

It has been observed that for the detection of fabric defect by 3DFT method, the values of radius of cylindrical filter and energy threshold are dependent on the fabric class and fabric defect to be detected. In fact, it is not possible to correlate unique optimum values of these two parameters with respect to all fabric class and all fabric defects. However, for a particular fabric class optimum values of these two parameters are determined by using the particle swarm optimization (PSO) method.
6.5.1. Selection of fitness function

It is desired to select optimum values of radius of cylindrical filter and energy threshold in such a way so that the error in defect detection (i.e., fitness function as defined on PSO technique) becomes minimum. For estimating the detection errors the template images are considered.

Let the synthetic fabric images shown in Figures 6.5(a) and (b) are the fabric frames of the 3D fabric image. The template images are the images from where global feature of grating structure is removed and binarization is done after required cylindrical band pass filtering. Thus the template images are the ideally reconstructed binary images of defect after proper filtering and thresholding. Two such binary template images are shown in figures 6.5(e) and (f), where the corresponding input fabric frames of the 3D fabric image are shown in figures 6.5(a) and (b). These template images are obtained by varying the radius and energy threshold values on a trial and error basis.

Let the template images for all filtered reconstructed fabric frames of \( q \) th fabric class are \( T_1^q, T_2^q, \ldots, T_L^q \). Since \( L \) numbers of input fabric frames are considered. For \( t \) th iteration of PSO, the binary fabric images of the filtered reconstructed fabric frames of \( q \) th fabric class corresponding to the obtained values of radius and energy threshold, are \( f_B^q(t)|_1, f_B^q(t)|_2, \ldots, f_B^q(t)|_L \).

Thus for the \( t \) th iteration of PSO, the fitness function, i.e., the error function becomes,

\[
\eta^q(t) = \sum_{k=1}^{L} [f_B^q(t)|_k - T_k^q]^2 \tag{6.10}
\]
Figure 6.5: (a) - (b) fabric images considered as the input frames of the 3D fabric image, (c) - (d) frequency domain response of 3D Fourier transform before filtering, (e) – (f) template images for (a) and (b) respectively.

6.5.2. Upgradation of position and velocity of the particles in swarm

A swarm of particles are considered. The dimension of each particle in the swarm is 2, as the numbers of parameters to be optimized are the radius of 3D cylindrical filter and energy threshold value. Let at $t$ th iteration the position vector of $i$ th particle in the search space be,
where, $POS_i(t)$ is the position vector of $i$th particle in the search space at $t$th iteration, $r_i(t), \theta_i(t)$ are values of radius of cylindrical filter and energy threshold of $i$th particle at $t$th iteration.

Now the position vector of each particle is updated in each iteration by using equations (3.28) to (3.33) of Chapter 3, till the iteration reaches to the maximum iteration $iter_{max}$.

Finally the radius of the cylindrical filter and energy threshold value corresponding to minimum fitness function, termed as global best (gBest) is selected as the optimum values of these two parameters for the fabric class and fabric defect under consideration. The algorithm of PSO for the selection of most optimum values of radius of 3D band pass cylindrical filter and energy threshold values is given in Appendix- 6.1.

### 6.6. Test results on TILDA database

The proposed method is tested on 10 types of fabric defects taking place on 5 fabric classes from TILDA database [118]. Images in TILDA database are 8 bit gray and of size (768×512) pixels. For convenience a fabric portion of size (512×512) is cropped. The fabric classes considered for the testing purpose are chosen in such a way so that they contain the stochastic components on a large scale. For the development of the 3D fabric image, along with the test fabric image four more fabric images of different orientations and containing different amount of stochastic components, are considered as reference images along the frame axis. Four reference fabric images of each fabric class are chosen. For fabric classes with more stochastic components, more numbers of reference fabric images may be considered along the frame axis. During the implementation of PSO, the numbers of particles are taken 10 and the maximum numbers of iterations are taken 100.
Visual images of the process are shown in Figures 6.6 to 6.10. Fabric classes shown in Figures 6.6 to 6.10 are represented as fabric classes 1 to 5. 1st row of each figure corresponds to input fabric frames, 2nd row of each figure gives the frequency domain response of the frames, 3rd row of each figure shows the filtered reconstructed fabric frames after 3D cylindrical filtering with optimum values of radius, 4th row of each figure gives the binary fabric image after suitable energy thresholding. The test results for various types of defects are shown in Table 6.1.

From the test result it is observed that out of 571 fabric samples of 5 fabric classes containing 10 types of fabric defects 534 fabric defects are detected properly at an apparent detection rate, as given by the ratio of the number of defective samples correctly detected to the total number of defective samples of 93.5%. The apparent detection success rate defined as the ratio of total number of samples correctly detected to the total number of samples is 93.5% when 79 more defect-free samples are also tested by the system making total number of samples tested as 650. The false alarm rate, defined as the ratio of numbers of defect free samples detected as defective to the total numbers of defect free samples is 6.33%. Thus from the test result true positive (TP), false positive (FP), false negative (FN) and true negative (TN) values are estimated as 93.5%, 6.33%, 6.5% and 93.67% respectively. Thus the actual detection success rate given by the ratio of summation of TP and TN to the summation of TP, FP, FN and TN becomes 93.6%.

Fast defect detection is possible by the proposed method, when input fabric frames are taken as the non overlapped fabric sub images of the same fabric sample. In this case the entire fabric image is processed simultaneously. One such example is shown in Figures- 6.13 to 6.16. The original fabric image of size (512×512) and its non overlapped partitioned sub images, considered as the input fabric frames of 3D fabric image are shown in Figures- 6.13(a) and (b) respectively. Dividing the fabric image shown in Figure 6.13(a) into (128×128) non
overlapped sub images, 16 input fabric frames are generated for 3D fabric image. These fabric frames are shown individually in Figure 6.14. The interlaced grating structure removed filtered reconstructed fabric frames are shown in Figure 6.15. Finally the binarized image obtained by suitable energy thresholding is shown in Figure 6.16. The optimum radius of cylindrical filter and energy threshold value are chosen by PSO technique. Studying figures 6.14 and 6.16 it becomes clear that the defects are detected at suitable reconstructed and thesholded output frames.

Figure 6.6 : Test result of first fabric class, First row is the five frame of fabrics with a defect in the third frame; Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering, whereas the fourth row is the image of defect identified in the corresponding frame
### Table 6.1: Test results on TILDA database

<table>
<thead>
<tr>
<th>Types of defects</th>
<th>Fabric class 1</th>
<th>Fabric class 2</th>
<th>Fabric class 3</th>
<th>Fabric class 4</th>
<th>Fabric class 5</th>
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<tr>
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<td>Samples tested</td>
<td>Defects detected</td>
<td>Samples tested</td>
<td>Defects detected</td>
<td>Samples tested</td>
</tr>
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<td>Oil mark/spot</td>
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<td>44</td>
<td>28</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Snarls/Loops/Float</td>
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<td>11</td>
<td>9</td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>Small holes</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Slub/Fly</td>
<td>15</td>
<td>13</td>
<td>28</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Thick yarn</td>
<td>10</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Thin places</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
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<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Broken pick</td>
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<td>0</td>
</tr>
<tr>
<td>Short pick</td>
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</tr>
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<td><strong>126</strong></td>
<td><strong>107</strong></td>
<td><strong>99</strong></td>
<td><strong>97</strong></td>
</tr>
</tbody>
</table>

*Table 6.1: Test results on TILDA database*
Figure 6.7: Test result for second fabric class. First row is the five frame of fabrics with a defect in the third frame; Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius, whereas the fourth row is the image of defect identified in the corresponding frame.
Figure 6.8: Test result for third fabric class. First row is the five frames of patterned fabrics with a defect in the third frame; Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius where the patterns are filtered out, whereas the fourth row is the image of defect identified in the corresponding frame.
Figure 6.9 : Test result for fourth fabric class. First row is the five frames of patterned fabrics with a defect in the third frame; Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius where the patterns are filtered out, whereas the fourth row is the image of defect identified in the corresponding frame.
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Figure 6.10: Test result for fifth fabric class. First row is the five frames of fine fabrics with a defect in the third frame; Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius, whereas the fourth row is the image of defect identified in the corresponding frame.
It has been observed that the developed system is also capable of detecting multiple defects at multiple fabric frames. This is shown in Figure 6.11.

Figure 6.11: Test result for multiple fabric defects. First row is the five frames of fine fabrics with defects in the second and third frames, Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius, whereas the fourth row is the image of defects identified in the corresponding frame.
The developed system is also capable of detecting very fine fabric defects, which is shown Figure 6.12.

*Figure- 6.12: Test result for very fine fabric defect, First row is the five frames of fine fabrics with fine defect in the third frame, Second row is the set of 3D Fourier transformed image; Third row is the frames of images after cylindrical filtering with optimum radius, whereas the fourth row is the image of defects identified in the corresponding frame*
Figure-6.13: (a) original fabric image; (b) partitioned image into sub-images of size (128×128)

Figure-6.14: Partitioned sub images of size (128×128) considered as input frames for 3D Fourier transform
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Figure 6.15: Partitioned sub images after cylindrical filtering of suitable radius

Figure 6.16: Partitioned sub images after suitable energy thresholding
Rearranging and reconstructing all the sub images of Figure 6.16, the image of the defect in the unpartitioned fabric image is shown in Figure- 6.17.

![Image of defect](image.png)

*Figure- 6.17: accumulation of thresholded reconstructed fabric frames, shown in figure- 6.16 to get the image of defect of fabric image shown in figure- 6.13(a).*

For the selection of size of non overlapped fabric sub images, two time factors are considered. The first time factor gives the time required to determine the 2DFT of the given fabric image, its filtering and reconstruction by suitable energy thresholding. The second time factor gives the time for partitioning the image for the development of 3D fabric image, 3DFT, cylindrical filtering and reconstruction of fabric frames by energy thresholding. The time complexity of 3DFT is less than 2DFT, provided the volume and area of the image is same in 3DFT and 2DFT respectively. The development of 3D fabric image by cropping large numbers of non overlapped fabric portions for 3DFT may make the defect detection by the proposed method more time consuming than 2DFT.

To demonstrate the fact the ratio of second time factor to the first is plotted against the single dimension of cropped, non overlapped, square fabric sub image in Figure 6.18. The fabric image shown in figure 6.13(a) is considered for the plot. As the ratio increases the time complexity for 3DFT increases with respect to the 2DFT. The ratio, more than 1, indicates that 3DFT is computationally more expensive than 2DFT technique.
Figure- 6.18: Plot of ratio of second time factor to the first against the single dimension of square fabric subimage

For a given fabric image, more numbers of fabric frames along frame axis means lesser size of each fabric frame. From the graph shown in figure- 6.18 it is clear that very low size of fabric frame is not recommended from the point of view of time complexity of the system.

6.7. Conclusion

The proposed method is based on 3D Fourier reconstruction of cylindrically filtered 3D fabric image where the radius of cylindrical filter and the energy threshold value required for extraction of defective fabric portion are chosen by particle swarm optimization technique. From the test results, it may be noted that the proposed method works satisfactorily for wide variety of fabric classes for the detection of fabric defects. For the entire 3D fabric image only one energy threshold value and a radius must be selected, as during the defect detection on test fabric image the defect may take place on any of the input fabric frames. The proposed method may efficiently be applied for the defect detection on real fabric sample, where the defect detection task may be made fast by simultaneous processing of non overlapped fabric
portions of bigger fabric sample. In case the defective fabric portion has sharper transition in intensity than the interlaced grating structure of fabric, high pass filtering should be done for the detection of fabric defect. The remaining methodologies remain identical. But as normally interlaced grating structure of fabric possesses sharper transition in intensity than the defective fabric portion, so in this work the band pass filtering is done.
Appendix- 6.1: PSO algorithm for the selection of most optimum values of radius of 3D band pass cylindrical filter and energy threshold values

**Input:** The 3D fabric image in the spatial domain.

**Output:** Optimized values of radius of 3D cylindrical filter and energy threshold value.

- **Initialize:** Number of particles, maximum numbers of iterations ($iter_{\text{max}}$), radius and energy threshold value of each particle within a minimum and maximum range (these are initialized with random values), velocity of the particles with random values within a minimum and maximum range, the binarized template images of different filtered reconstructed fabric frames of a fabric class.

- Set dimension of each particle equal to the variables to be optimized.

- **While** ($iteration(t) \leq iter_{\text{max}}$) {

  i) Find out fitness function of each particle corresponding to the values of radius and energy threshold at $t$ th iteration.

  ii) Update the values of velocities and hence the values of radius and energy threshold of each particle by using equations (3.28) to (3.33) of chapter 3.

} end while

The radius of cylindrical filter and energy threshold value corresponding to the minimum fitness function i.e., gBest is finally selected as the most optimum values of these two parameters.