Textile Quality Control System

Technical Datasheet for PDF Report Interpretation

Textile Engineering Solutions

Document Version 1.1.0

Contents

1 Document Overview

This datasheet provides complete technical reference for interpreting the **Color Analysis Report** PDF generated by the Textile Quality Control System.

1.1 Report Structure

The PDF report is organized in the following order:

1. **Cover Page** - Logo, company info, report metadata, executive summary
2. **Analysis Settings** (optional) - All parameters used
3. **Color Unit** - Color measurements and differences
4. **Pattern Unit** - Structural pattern analysis
5. **Advanced Texture Analysis** - FFT, Gabor, GLCM, LBP, Wavelet
6. **Pattern Repetition Unit** - Pattern count and integrity
7. **Spectrophotometer Simulation** - Professional color metrics
8. **Conclusion & Decision** - Final recommendation

1.2 Status Color Codes

Status	Color	Meaning
PASS	Green	Within acceptable tolerance
CONDITIONAL	Orange	Near limits, requires monitoring
FAIL	Red	Outside tolerance, action required

1.3 Images Overview

The report contains 22 visualization images. Each is explained in detail in this document:

Image #	Name	Section
1	Spectral Analysis (Proxy)	Color Unit
2	Visual Difference Analysis	Color Unit
3	Lab* Visualizations	Color Unit
4	Histograms (RGB)	Pattern Unit
5	Fourier Domain Analysis	Advanced Texture
6	Gabor Filter Bank (Montage)	Advanced Texture
7	Gabor Energy Distribution	Advanced Texture
8	GLCM Texture Features	Advanced Texture
9	Local Binary Patterns (LBP)	Advanced Texture
10	Wavelet Decomposition	Advanced Texture
11	Line Angle Distribution	Advanced Texture
12	Defect Detection & Saliency	Advanced Texture
13	Pattern Detection Maps	Pattern Repetition
14	Pattern Count Comparison	Pattern Repetition
15	Blob Detection Results	Pattern Repetition
16	Keypoint Matching Analysis	Pattern Repetition

Image #	Name	Section
17	Auto-correlation Analysis	Pattern Repetition
18	Spatial Distribution Analysis	Pattern Repetition
19	Pattern Integrity Assessment	Pattern Repetition
20	Pattern Size Comparison	Pattern Repetition
21	Missing/Extra Patterns Catalog	Pattern Repetition
22	Metamerism Analysis	Spectrophotometer

2 Cover Page Elements

2.1 Report Metadata

Field	Description
Report Date	Timestamp when analysis was performed (configurable timezone)
Operator	Name of the person running the analysis
Analysis ID	Unique identifier: `SPEC_YYYYMMDD_HHMMSS`
Software Version	Current version of the analysis system

2.2 Executive Summary Table

The executive summary provides quick PASS/FAIL status:

Metric	How to Read
Color Score	Score out of 100. Higher is better. ≥ 70 typically PASS.
Pattern Score (SSIM)	Structural similarity %. Higher is better. ≥ 90 typically PASS.
ΔE_{2000} (Mean)	Color difference. Lower is better. < 2.0 typically PASS.
Overall Score	Average of Color and Pattern scores.

3 Color Space Conversions

3.1 RGB to XYZ Conversion (sRGB to CIE XYZ)

Step 1: Linearize sRGB values

For each channel $C \in \{R, G, B\}$:

$$C_{linear} = \begin{cases} \dfrac{C_{sRGB}/255}{12.92} & \text{if } C_{sRGB}/255 \leq 0.04045 \\ \left(\dfrac{C_{sRGB}/255 + 0.055}{1.055}\right)^{2.4} & \text{otherwise} \end{cases} \tag{1}$$

Step 2: Apply transformation matrix (D65 illuminant)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = 100 \times \begin{bmatrix} 0.4124564 & 0.3575761 & 0.1804375 \\ 0.2126729 & 0.7151522 & 0.0721750 \\ 0.0193339 & 0.1191920 & 0.9503041 \end{bmatrix} \begin{bmatrix} R_{linear} \\ G_{linear} \\ B_{linear} \end{bmatrix} \tag{2}$$

3.2 XYZ to Lab* Conversion

Step 1: Calculate ratios

$$X_r = \frac{X}{X_n}, \quad Y_r = \frac{Y}{Y_n}, \quad Z_r = \frac{Z}{Z_n} \tag{3}$$

Where (X_n, Y_n, Z_n) is the reference white point. For D65: $(95.047, 100.000, 108.883)$

Step 2: Apply function f

$$f(t) = \begin{cases} t^{1/3} & \text{if } t > \delta^3 \\ \dfrac{t}{3\delta^2} + \dfrac{4}{29} & \text{otherwise} \end{cases} \quad \text{where } \delta = \frac{6}{29} \tag{4}$$

Step 3: Calculate Lab* values

$$\boxed{L^* = 116 \cdot f(Y_r) - 16} \tag{5}$$

$$\boxed{a^* = 500 \cdot (f(X_r) - f(Y_r))} \tag{6}$$

$$\boxed{b^* = 200 \cdot (f(Y_r) - f(Z_r))} \tag{7}$$

Interpretation:

- L^*: Lightness (0 = black, 100 = white)
- a^*: Green-Red axis (negative = green, positive = red)
- b^*: Blue-Yellow axis (negative = blue, positive = yellow)

3.3 RGB to CMYK Conversion

$$K = 1 - \max(R', G', B') \quad \text{where } R' = R/255,\ G' = G/255,\ B' = B/255 \tag{8}$$

$$C = \frac{1 - R' - K}{1 - K}, \quad M = \frac{1 - G' - K}{1 - K}, \quad Y = \frac{1 - B' - K}{1 - K} \tag{9}$$

Values are multiplied by 100 to show as percentages in the report.

4 Color Difference Formulas (ΔE)

4.1 CIE76 (ΔE_{76})

The simplest Euclidean distance in Lab* space:

$$\boxed{\Delta E_{76} = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2}} \tag{10}$$

When to use: Quick assessment, historical data comparison.

4.2 CIE94 (ΔE_{94})

Improved formula with weighting factors:

$$\Delta E_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L \cdot S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C \cdot S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H \cdot S_H}\right)^2} \tag{11}$$

Where:

$$S_L = 1 \tag{12}$$
$$S_C = 1 + K_1 \cdot C^*_1 \quad (K_1 = 0.045) \tag{13}$$
$$S_H = 1 + K_2 \cdot C^*_1 \quad (K_2 = 0.015) \tag{14}$$

Chroma: $C^* = \sqrt{a^{*2} + b^{*2}}$
Hue difference: $\Delta H^*_{ab} = \sqrt{\Delta a^{*2} + \Delta b^{*2} - \Delta C^{*2}}$

4.3 CIEDE2000 (ΔE_{00})

The most accurate and recommended formula:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \tag{15}$$

Key corrections:

- G factor: Adjusts a^* in neutral colors
- T factor: Accounts for hue-dependent perception
- R_T: Rotation term for blue region

Modified a':

$$a' = (1 + G) \cdot a^* \quad \text{where } G = 0.5 \left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right) \tag{16}$$

4.4 CMC (ΔE_{CMC})

Color Measurement Committee formula with l:c ratio (typically 2:1 or 1:1):

$$\Delta E_{CMC} = \sqrt{\left(\frac{\Delta L^*}{l \cdot S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{c \cdot S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2} \tag{17}$$

Where:

$$S_L = \begin{cases} 0.511 & \text{if } L^* < 16 \\ \dfrac{0.040975 \cdot L^*}{1 + 0.01765 \cdot L^*} & \text{otherwise} \end{cases} \tag{18}$$

$$S_C = \frac{0.0638 \cdot C^*_1}{1 + 0.0131 \cdot C^*_1} + 0.638 \tag{19}$$

4.5 ΔE Interpretation Guide

ΔE Value	Interpretation
< 1.0	Not perceptible by human eye
$1.0 - 2.0$	Perceptible through close observation
$2.0 - 3.5$	Perceptible at a glance
$3.5 - 5.0$	Clear noticeable difference
> 5.0	Colors appear more different than similar

Default thresholds in the system:

- PASS: $\Delta E < 2.0$
- CONDITIONAL: $2.0 \leq \Delta E \leq 3.5$
- FAIL: $\Delta E > 3.5$

5 Color Measurements Table

5.1 How to Read the Color Measurements Section

The system samples 5 points across the image in a grid pattern:

$$\text{Grid positions: } (y, x) = (0.2h + 0.15ih,\ 0.2w + 0.15iw) \quad i \in \{0, 1, 2, 3, 4\} \tag{20}$$

5.2 RGB Color Values Table

Column	Description
Region	Sample point number (1-5)
Position	(x, y) pixel coordinates
Ref R/G/B	Reference image RGB values (0-255)
Test R/G/B	Sample image RGB values (0-255)

Reading tip: Compare Ref and Test columns. Large differences indicate color deviation at that point.

5.3 Lab* Color Space Values Table

Column	Description
Ref/Test L^*	Lightness (0-100). Higher = lighter.
Ref/Test a^*	Green-Red axis. Negative = green, Positive = red.
Ref/Test b^*	Blue-Yellow axis. Negative = blue, Positive = yellow.

5.4 Color Difference Metrics Table

Shows ΔE at each sample point:

Column	Description
ΔE_{76}	CIE76 color difference (simplest)
ΔE_{94}	CIE94 color difference (improved)
ΔE_{2000}	CIEDE2000 color difference (most accurate)
Status	PASS/CONDITIONAL/FAIL based on ΔE_{2000}

6 Color Quality Indices

6.1 Uniformity Index

Measures how consistent the color is across the sample:

$$\boxed{\text{Uniformity Index} = \max(0,\ 100 - \sigma_{\Delta E} \times k)} \tag{21}$$

Where:

- $\sigma_{\Delta E}$ = Standard deviation of ΔE values across pixels
- k = Uniformity multiplier (default: 10)

Interpretation:

- ≥ 85: Excellent uniformity (PASS)
- $70 - 85$: Acceptable (CONDITIONAL)
- < 70: Poor uniformity (FAIL)

6.2 Metamerism Index

Measures color consistency across different illuminants (D65, TL84, A):

$$\boxed{\text{Metamerism Index} = 10 \times \sigma(\Delta E_{D65}, \Delta E_{TL84}, \Delta E_A)} \tag{22}$$

Interpretation:

- < 2.0: Low metamerism (PASS)
- $2.0 - 5.0$: Moderate metamerism (CONDITIONAL)
- > 5.0: High metamerism risk (FAIL)

6.3 Whiteness Index (CIE, ISO 11475)

For white/near-white samples:

$$\boxed{W = Y + 800(x_n - x) + 1700(y_n - y)} \tag{23}$$

Where (x, y) are chromaticity coordinates and $(x_n, y_n) = (0.3138, 0.3310)$ for D65/10°.
Tint:

$$T = 900(x_n - x) - 650(y_n - y) \tag{24}$$

6.4 Yellowness Index (ASTM E313)

$$\boxed{YI = 100 \times \frac{C_x \cdot X - C_z \cdot Z}{Y}} \tag{25}$$

Where $C_x = 1.3013$ and $C_z = 1.1498$ for D65/10°.

7 Scoring System

7.1 Color Score

$$\boxed{\text{Color Score} = \max(0,\ 100 - \bar{\Delta E}_{76} \times k_c)} \tag{26}$$

Where:

- $\bar{\Delta E}_{76}$ = Mean CIE76 color difference
- k_c = Color score multiplier (default: 20)

7.2 Pattern Score

$$\boxed{\text{Pattern Score} = \text{SSIM} \times 100} \tag{27}$$

Where SSIM is the Structural Similarity Index (see Section **??**).

7.3 Overall Score

$$\boxed{\text{Overall Score} = \frac{\text{Color Score} + \text{Pattern Score}}{2}} \tag{28}$$

7.4 Decision Logic

Decision	Criteria
ACCEPT	Color Score ≥ 70 AND Pattern Score ≥ 90 AND Pattern Repetition OK
CONDITIONAL ACCEPT	Overall Score ≥ 70 OR Pattern Repetition = CONDITIONAL
REJECT	Otherwise

8 IMAGE 1: Spectral Analysis (Proxy)

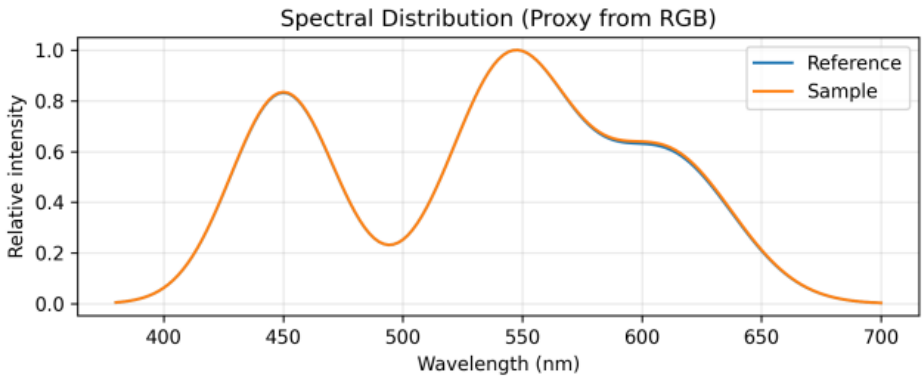

Figure 1: Spectral Analysis (Proxy from RGB)

8.1 What This Image Shows

This chart approximates spectral reflectance curves from RGB values. Since RGB images don't contain true spectral data, the system creates a proxy using Gaussian functions centered at primary wavelengths.

8.2 How It's Calculated

The proxy curve is built from three Gaussian functions:

$$\text{Red basis:} \quad G_R(\lambda) = e^{-0.5((\lambda-610)/28)^2} \tag{29}$$

$$\text{Green basis:} \quad G_G(\lambda) = e^{-0.5((\lambda-545)/25)^2} \tag{30}$$

$$\text{Blue basis:} \quad G_B(\lambda) = e^{-0.5((\lambda-450)/22)^2} \tag{31}$$

Combined curve:

$$S(\lambda) = \frac{R \cdot G_R(\lambda) + G \cdot G_G(\lambda) + B \cdot G_B(\lambda)}{\max} \tag{32}$$

8.3 How to Read This Image

- **X-axis:** Wavelength in nanometers (380-700nm visible spectrum)
- **Y-axis:** Relative intensity (normalized 0-1)
- **Green line:** Reference sample spectral proxy
- **Red/Orange line:** Test sample spectral proxy

8.4 Interpretation Guide

Pattern Observed	Interpretation
Lines overlap closely	Colors match well across spectrum
Peak shift left/right	Hue difference (color shift)
Peak height difference	Saturation/intensity difference
Different peak widths	One sample has purer/narrower color
Multiple peaks misaligned	Complex color mismatch
Blue region (400-500nm) difference	Blue/purple tint variation
Green region (500-570nm) difference	Green tint variation
Red region (600-700nm) difference	Red/orange tint variation

8.5 Limitations

This is an **approximation only**. For true spectral analysis, use spectrophotometer data in CSV format. RGB cameras cannot capture the full spectral information that a spectrophotometer provides.

9 IMAGE 2: Visual Difference Analysis

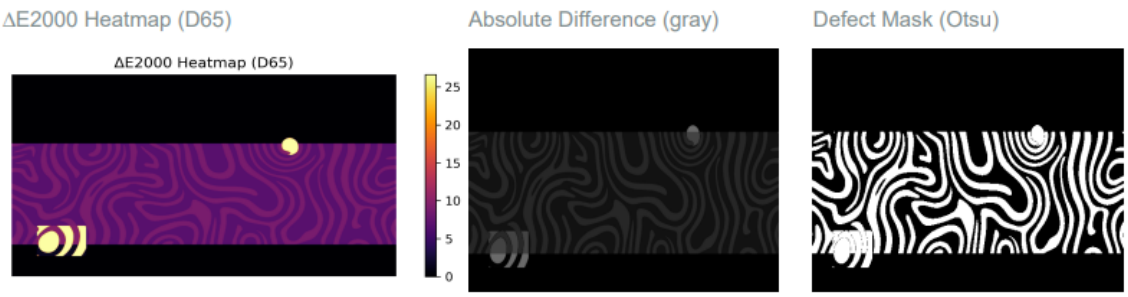

Figure 2: Visual Difference Analysis (3 merged images)

This image contains three visualizations merged together:

9.1 Part A: ΔE_{2000} Heatmap

What it shows: Pixel-by-pixel color difference map using the CIEDE2000 formula.
Color scale (Inferno colormap):

- **Black/Dark purple:** Low ΔE (< 1) - Excellent match
- **Red/Orange:** Moderate ΔE (1-3) - Perceptible difference
- **Yellow/White:** High ΔE (> 3) - Significant difference

How to read:

- Look for **hot spots** (bright areas) - these indicate color problems
- Uniform dark color = consistent color match
- Patterns of bright areas may indicate systematic issues
- Edge artifacts are normal and can be ignored

9.2 Part B: Absolute Difference (Grayscale)

What it shows: Simple pixel-by-pixel absolute difference in grayscale.

$$D(x, y) = |I_{ref}(x, y) - I_{sample}(x, y)| \tag{33}$$

How to read:

- **Black pixels:** No difference (perfect match)
- **Gray pixels:** Some difference
- **White pixels:** Maximum difference

9.3 Part C: Defect Mask (Otsu Threshold)

What it shows: Binary mask highlighting potential defects using automatic thresholding.

How to read:

- **Black areas:** Normal (within threshold)
- **White areas:** Potential defects or significant differences

Defect Density calculation:

$$\text{Defect Density} = \frac{\text{White pixels}}{\text{Total pixels}} \times 10000 \tag{34}$$

9.4 Interpretation Table

Pattern Observed	Possible Cause / Action
Uniform slight difference	Normal process variation - monitor
Hot spots in center	Uneven dyeing - check bath circulation
Hot spots at edges	Edge effects - may need to exclude from analysis
Streaks or lines	Print head issues or fabric tension problems
Random scattered spots	Contamination or fiber irregularity
Large bright regions	Major color mismatch - reject and investigate

10 IMAGE 3: Lab* Visualizations

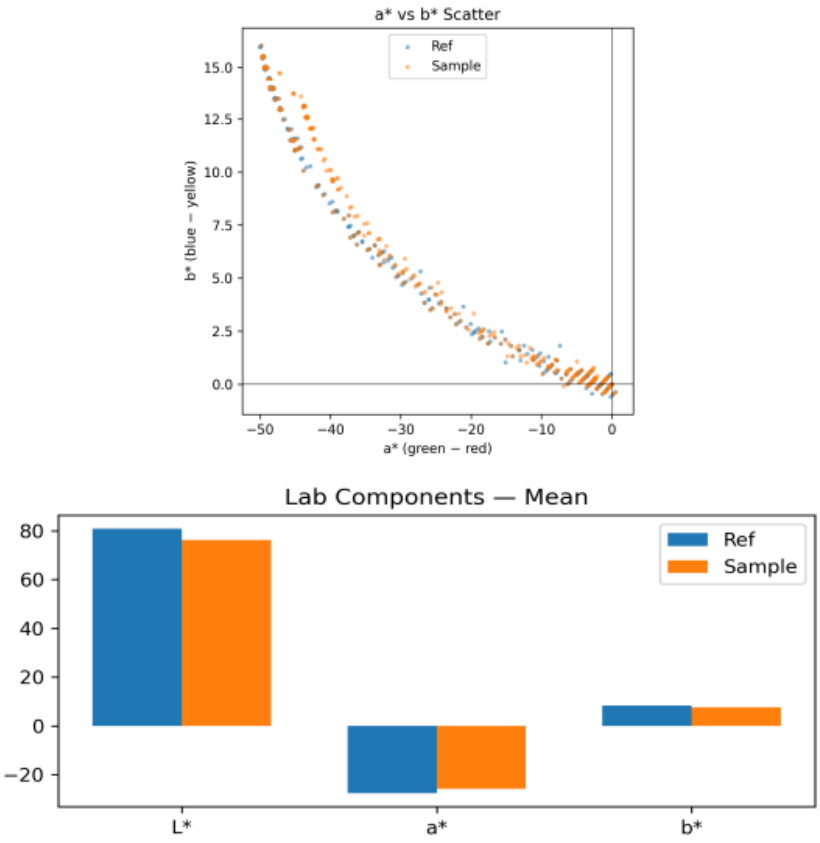

Figure 3: Lab* Visualizations (2 merged images)

This image contains two Lab* color space visualizations:

10.1 Part A: a*-b* Scatter Plot

What it shows: Distribution of colors in the chromatic plane (a* vs b*).

Axes meaning:

- **Horizontal (a*):** Green (−) to Red (+)
- **Vertical (b*):** Blue (−) to Yellow (+)
- **Origin (0,0):** Neutral gray (no color)

Point colors:

- **Green points:** Reference sample pixels
- **Red points:** Test sample pixels

How to read:

- **Overlapping clouds:** Good color match
- **Separated clouds:** Color shift (hue difference)
- **Cloud shape difference:** Different color distribution/saturation
- **Distance from origin:** Chroma (color intensity)

10.2 Part B: L*a*b* Component Bar Chart

What it shows: Mean values of each Lab* component for Reference vs Sample.

Bars:

- **Left bar (each pair):** Reference
- **Right bar (each pair):** Sample

How to read:

- Compare bar heights for each component
- L^* difference: Sample is lighter/darker
- a^* difference: Sample is more red/green
- b^* difference: Sample is more yellow/blue

10.3 Interpretation Examples

Observation	Meaning
Sample L^* higher	Sample is lighter than reference
Sample a^* more positive	Sample is more red/less green
Sample b^* more negative	Sample is more blue/less yellow
Both clouds near origin	Neutral/gray colors
Large cloud spread	High color variation in sample

11 IMAGE 4: Histograms (RGB)

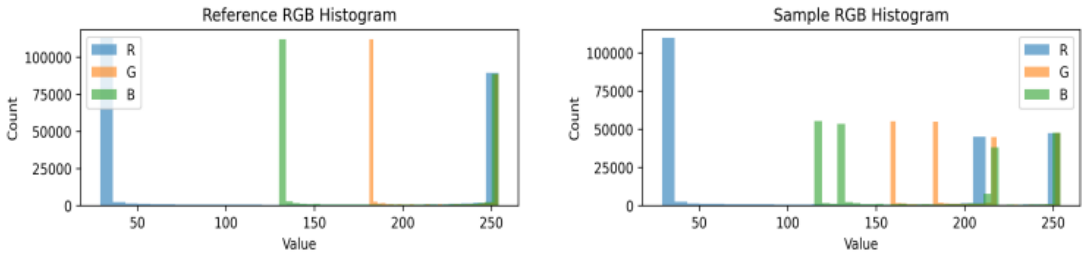

Figure 4: RGB Histograms (2 merged images: Reference and Sample)

11.1 What This Image Shows

Side-by-side RGB histograms showing the distribution of pixel values in each color channel.

11.2 How to Read RGB Histograms

For each histogram:

- **X-axis:** Pixel value (0-255)
- **Y-axis:** Count (number of pixels with that value)
- **Red line:** Red channel distribution
- **Green line:** Green channel distribution
- **Blue line:** Blue channel distribution

11.3 Interpretation Guide

Pattern	Interpretation
Similar shapes in both	Good color reproduction
Peak position shift	Color bias/cast
Narrower distribution	More uniform color
Wider distribution	More color variation
Clipping at 0 or 255	Under/over exposure or saturation
Multiple peaks	Multi-colored sample or pattern
Reference-Sample comparison:	
Same peak positions	Matching colors
Sample peaks shifted right	Sample is brighter
Sample peaks shifted left	Sample is darker
Channel ratio change	Hue shift

11.4 Common Patterns

- **All channels aligned:** Neutral/gray sample
- **Red dominant:** Warm tones
- **Blue dominant:** Cool tones

- **Sharp single peak:** Uniform solid color
- **Broad distribution:** Complex/varied colors

12 IMAGE 5: Fourier Domain Analysis

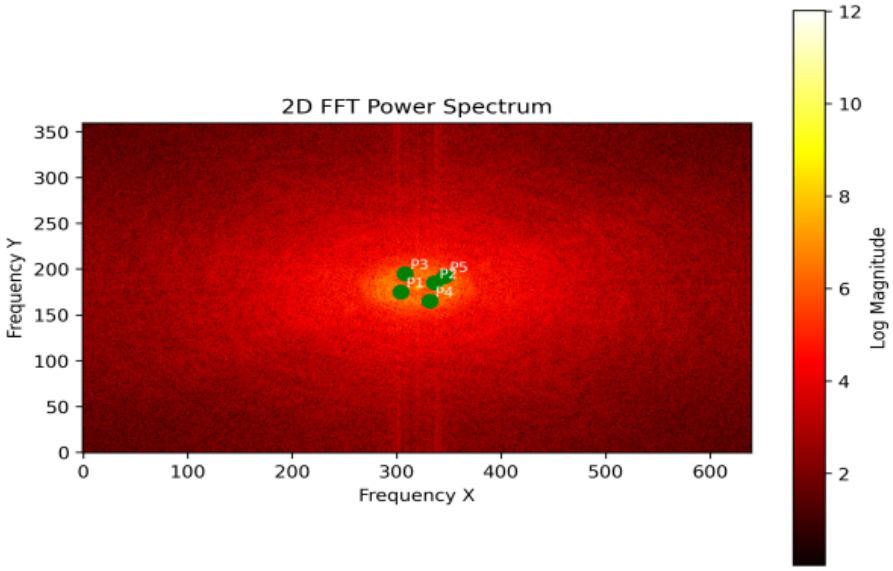

Figure 5: 2D FFT Power Spectrum

12.1 What This Image Shows

2D Fast Fourier Transform power spectrum reveals periodic structures and directional patterns in the fabric texture.

12.2 How It's Calculated

$$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \cdot e^{-i2\pi(ux/M+vy/N)} \tag{35}$$

Power spectrum (log scale for visibility):

$$P(u,v) = \log(|F(u,v)| + 1) \tag{36}$$

12.3 How to Read This Image

- **Center:** DC component (average brightness) - masked out
- **Distance from center:** Frequency (farther = finer detail)
- **Angle from center:** Orientation of pattern
- **Bright spots:** Dominant frequencies (periodic patterns)
- **Green markers (P1, P2, etc.):** Detected peaks

12.4 Interpretation Guide

Pattern Observed	Interpretation
Central bright spot only	No periodic pattern (random texture)
Symmetric bright spots	Regular repeating pattern
Spots on horizontal line	Vertical stripes in fabric
Spots on vertical line	Horizontal stripes in fabric
Spots at 45° angles	Diagonal pattern (twill weave)
Ring pattern	Pattern at specific frequency
Star/cross pattern	Grid or checkerboard pattern
Diffuse glow	Random texture, no dominant period

12.5 Key Metrics from FFT

Metric	Meaning
Fundamental Period	Repeat distance in pixels: $\frac{\min(H,W)}{r_{peak}}$
Dominant Orientation	Main direction of pattern (degrees)
Anisotropy Ratio	How directional the pattern is (higher = more directional)

13 IMAGE 6: Gabor Filter Bank (Montage)

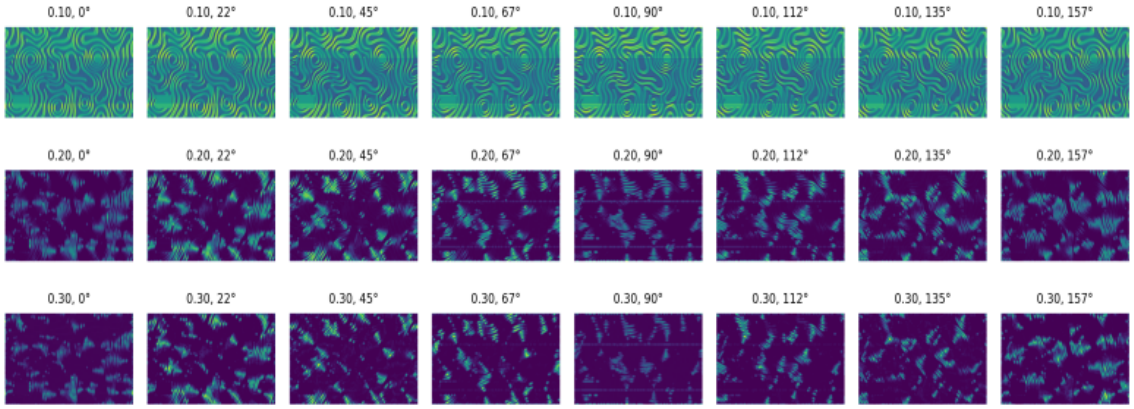

Figure 6: Gabor Filter Bank Responses (24 small images)

13.1 What This Image Shows

A montage of texture responses from Gabor filters at different frequencies and orientations.

13.2 How Gabor Filters Work

Gabor filter:

$$g(x, y; \lambda, \theta, \sigma) = \exp\left(-\frac{x'^2 + y'^2}{2\sigma^2}\right) \cos\left(\frac{2\pi x'}{\lambda}\right) \tag{37}$$

Where:

$$x' = x\cos\theta + y\sin\theta \tag{38}$$

$$y' = -x\sin\theta + y\cos\theta \tag{39}$$

13.3 How to Read This Image

Grid organization:

- **Rows:** Different frequencies (fine to coarse)
- **Columns:** Different orientations (0° to 157.5°)
- **Each cell:** Filter response (energy map)

Cell brightness:

- **Bright areas:** Strong response (pattern matches filter)
- **Dark areas:** Weak response (no matching pattern)

13.4 Interpretation Guide

Pattern Observed	Interpretation
One cell much brighter	Dominant texture at that frequency/orientation
Entire row bright	Pattern at specific frequency
Entire column bright	Pattern at specific orientation
All cells similar	Isotropic (no directional) texture
Diagonal bright pattern	Angled weave structure
Checkerboard brightness	Complex multi-scale pattern

14 IMAGE 7: Gabor Energy Distribution

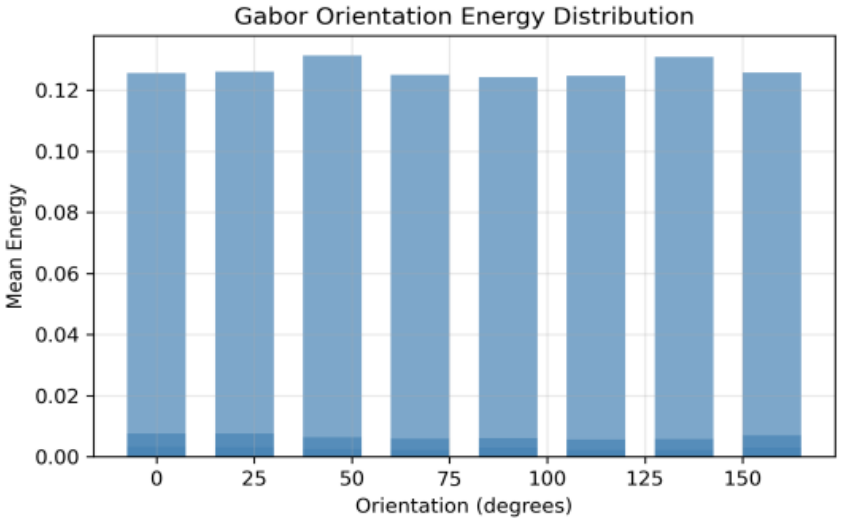

Figure 7: Gabor Orientation Energy Distribution

14.1 What This Image Shows

Bar chart showing the mean energy response at each orientation angle across all frequencies.

14.2 How to Read This Chart

- **X-axis:** Orientation angle (degrees, 0° to 180°)
- **Y-axis:** Mean energy response
- **Taller bars:** Stronger pattern at that orientation

14.3 Interpretation Guide

Pattern Observed	Interpretation
Single dominant peak	Strong directional pattern (e.g., stripes)
Two peaks 90° apart	Grid or crosshatch pattern
Flat distribution	Isotropic texture (no preferred direction)
Peak at 0°	Vertical pattern dominates
Peak at 90°	Horizontal pattern dominates
Peak at 45°/135°	Diagonal pattern (twill weave)

14.4 Key Metrics

- **Dominant Orientation:** Angle with highest energy
- **Coherency:** $\frac{\max(\text{energy})}{\text{mean}(\text{energy})}$ - higher means more directional

15 IMAGE 8: GLCM Texture Features

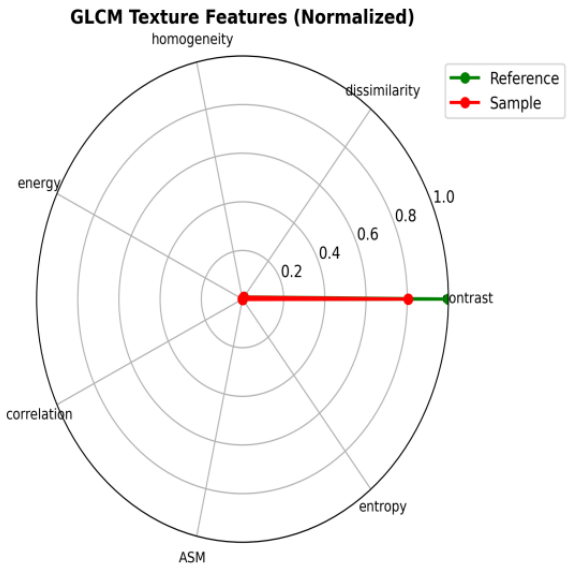

Figure 8: GLCM Texture Features (Radar Chart)

15.1 What This Image Shows

Radar (spider) chart comparing GLCM texture features between Reference and Sample.

15.2 GLCM Features Explained

Feature	What It Measures
Contrast	Amount of local variation. High = high texture contrast.
Dissimilarity	Difference between neighboring pixels.
Homogeneity	Closeness to diagonal. High = uniform texture.
Energy (ASM)	Uniformity/orderliness. High = regular pattern.
Correlation	Linear dependency of gray levels.
Entropy	Randomness/complexity. High = complex texture.

15.3 How to Read This Chart

- **Green polygon:** Reference sample
- **Red polygon:** Test sample
- **Each axis:** One GLCM feature (normalized 0-1)
- **Distance from center:** Feature value

15.4 Interpretation Guide

Observation	Interpretation
Shapes overlap	Similar texture characteristics
Green larger on contrast	Reference has more texture contrast
Red larger on homogeneity	Sample is more uniform
Red larger on entropy	Sample is more complex/random
Different shapes	Fundamentally different textures

15.5 Z-Score Interpretation

The table also shows z-scores for each feature:

$$z = \frac{\text{Sample value} - \text{Reference value}}{\text{typical std}} \tag{40}$$

- $|z| < 2$: Similar textures
- $2 \leq |z| < 3$: Moderate difference
- $|z| \geq 3$: Significant difference

16 IMAGE 9: Local Binary Patterns (LBP)

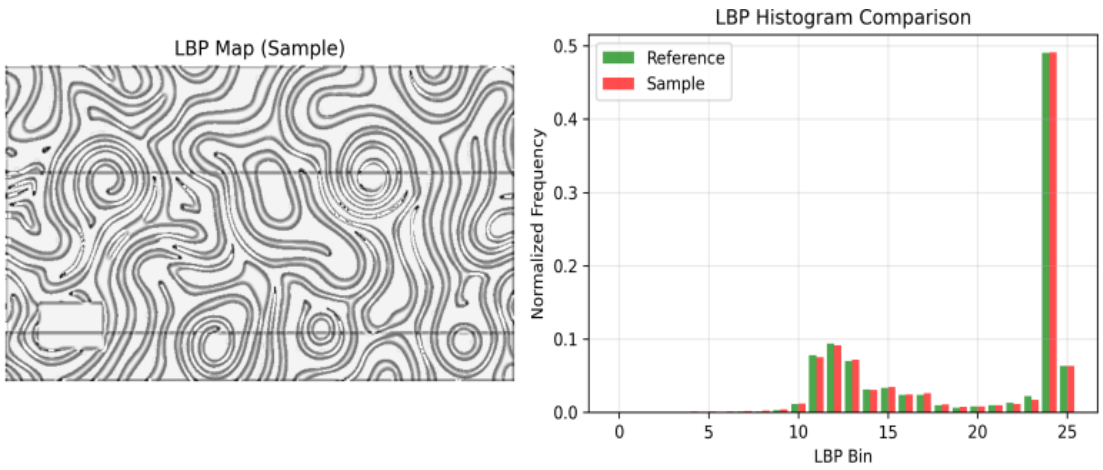

Figure 9: LBP Map and Histogram Comparison (2 merged images)

16.1 What This Image Shows

Part A: LBP texture map of the sample image
Part B: Histogram comparison of LBP patterns between Reference and Sample

16.2 How LBP Works

For each pixel, compare to P neighbors at radius R:

$$\text{LBP}_{P,R}(x_c, y_c) = \sum_{p=0}^{P-1} s(g_p - g_c) \cdot 2^p \tag{41}$$

Where $s(x) = 1$ if $x \geq 0$, else 0.
Default parameters: $P = 24$ neighbors, $R = 3$ pixels radius.

16.3 How to Read the LBP Map

- Different gray levels = different local texture patterns
- Uniform areas = consistent texture
- Varying areas = complex texture
- Edges appear as specific LBP values

16.4 How to Read the Histogram

- **X-axis:** LBP bin (pattern type)
- **Y-axis:** Normalized frequency
- **Green bars:** Reference
- **Red bars:** Sample

16.5 Interpretation Guide

Observation	Interpretation
Histograms overlap	Very similar textures
Different peak positions	Different dominant patterns
Wider histogram	More texture variety
Narrow histogram	More uniform texture

16.6 Distance Metrics

- **Chi-squared distance:** $\chi^2 = \frac{1}{2}\sum_i \frac{(h_1(i)-h_2(i))^2}{h_1(i)+h_2(i)}$
- **Bhattacharyya distance:** $D_B = -\ln \sum_i \sqrt{h_1(i) \cdot h_2(i)}$

Lower values = more similar textures.

17 IMAGE 10: Wavelet Decomposition

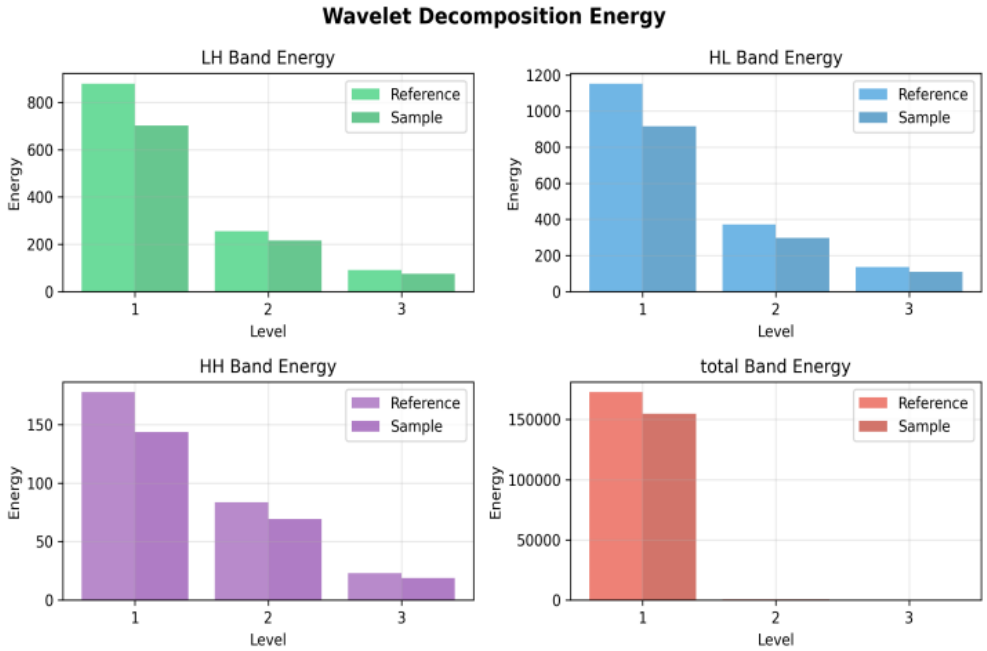

Figure 10: Wavelet Energy Comparison (4 merged charts)

17.1 What This Image Shows

Energy distribution at different wavelet decomposition levels and frequency bands.

17.2 Wavelet Bands Explained

Band	What It Captures
LL	Low frequency (approximation) - overall structure
LH	Horizontal details (vertical edges)
HL	Vertical details (horizontal edges)
HH	Diagonal details

17.3 How to Read These Charts

- **X-axis:** Decomposition level (1 = finest, 3 = coarsest)
- **Y-axis:** Energy value
- **Colored bars:** Reference (light) vs Sample (dark)

17.4 Interpretation Guide

Observation	Interpretation
Similar bar heights	Matching texture at that scale
Sample LH higher	Sample has more horizontal detail
Sample HL higher	Sample has more vertical detail
Sample HH higher	Sample has more diagonal texture
Higher at level 1	Fine detail difference
Higher at level 3	Coarse structure difference

17.5 Energy Ratio

For each band:

$$\text{Ratio} = \frac{E_{\text{sample}}}{E_{\text{reference}}} \tag{42}$$

- Ratio ≈ 1.0: Similar texture energy
- Ratio > 1.0: Sample has more texture at that scale
- Ratio < 1.0: Sample has less texture at that scale

18 IMAGE 11: Line Angle Distribution

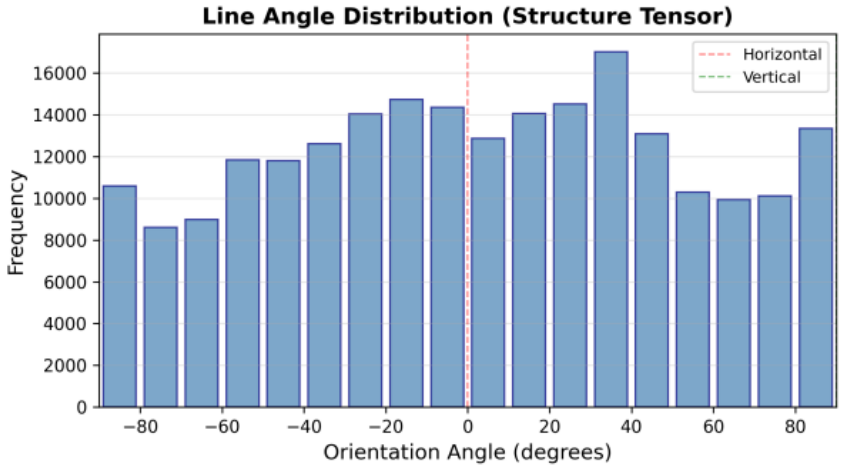

Figure 11: Line Angle Distribution (Structure Tensor)

18.1 What This Image Shows

Histogram of local orientation angles calculated from the structure tensor.

18.2 How It's Calculated

Structure tensor:

$$J = \begin{bmatrix} \langle I_x^2 \rangle & \langle I_x I_y \rangle \\ \langle I_x I_y \rangle & \langle I_y^2 \rangle \end{bmatrix} \tag{43}$$

Orientation:

$$\theta = \frac{1}{2} \arctan\left(\frac{2\langle I_x I_y \rangle}{\langle I_x^2 \rangle - \langle I_y^2 \rangle} \right) \tag{44}$$

18.3 How to Read This Chart

- **X-axis:** Orientation angle (-90° to +90°)
- **Y-axis:** Frequency (count of pixels at that angle)
- **Reference lines:** 0° (horizontal) and ±90° (vertical)

18.4 Interpretation Guide

Pattern	Interpretation
Peak at 0°	Dominant horizontal structures
Peak at ±90°	Dominant vertical structures
Peak at 45° or -45°	Diagonal pattern (twill weave)
Flat distribution	Isotropic texture (no preferred direction)
Multiple peaks	Multiple orientations (complex weave)
Sharp single peak	Strong directional texture

18.5 Related Metrics

- **Mean Coherency:** How well-defined the orientation is (0-1)
- **HOG Edge Density:** Overall amount of edge structure

19 IMAGE 12: Defect Detection & Saliency Map

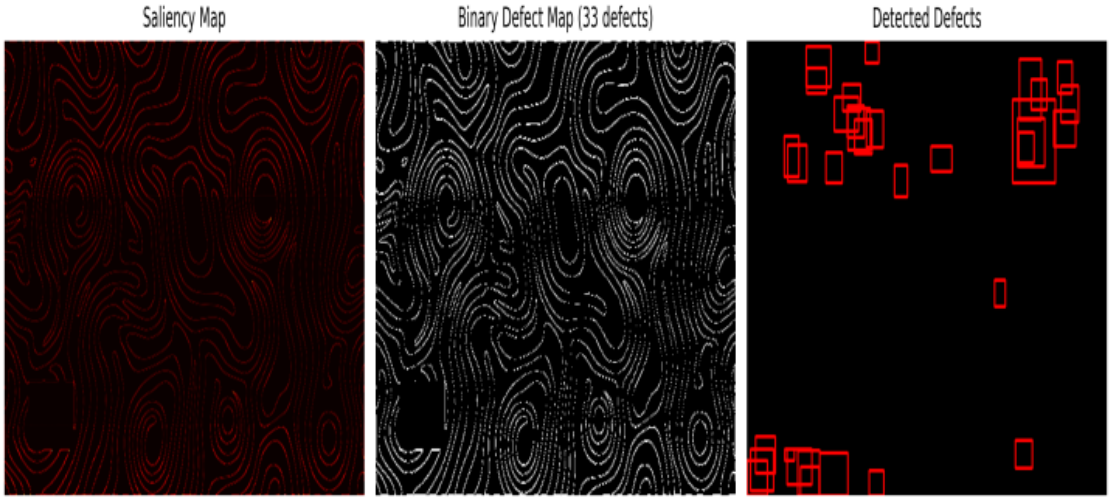

Figure 12: Defect Detection (3 merged images)

19.1 What This Image Shows

Three visualizations for defect detection:

- **Part A:** Saliency Map (heat map)
- **Part B:** Binary Defect Map
- **Part C:** Detected Defects Overlay

19.2 Saliency Map Calculation

Using spectral residual method:

$$R(f) = \log|F(f)| - G * \log|F(f)| \tag{45}$$

$$\text{Saliency} = \left|\text{IFFT2D}\left(e^{R(f)+i\Phi(f)}\right)\right|^2 \tag{46}$$

19.3 How to Read Each Part

Part A - Saliency Map:

- **Dark areas:** Normal/expected regions
- **Bright/hot areas:** Anomalous regions (potential defects)
- Uses "hot" colormap (black → red → yellow → white)

Part B - Binary Defect Map:

- **Black:** Normal areas
- **White:** Potential defect areas (above Otsu threshold)

Part C - Detected Defects:

- Red rectangles around each detected defect
- Shows bounding boxes for individual defects

19.4 Interpretation Guide

Observation	Interpretation
No bright spots	Clean sample, no defects
Scattered small spots	Minor imperfections or noise
Large bright region	Significant defect area
Linear bright pattern	Streak or scratch
Periodic bright spots	Pattern defect (missing elements)
Edge-only brightness	May be alignment artifact

19.5 Defect Catalog

The report includes a table with:

- ID number
- Type (Anomaly)
- Area in pixels
- Bounding box coordinates (x0, y0, x1, y1)

20 IMAGE 13: Pattern Detection Maps

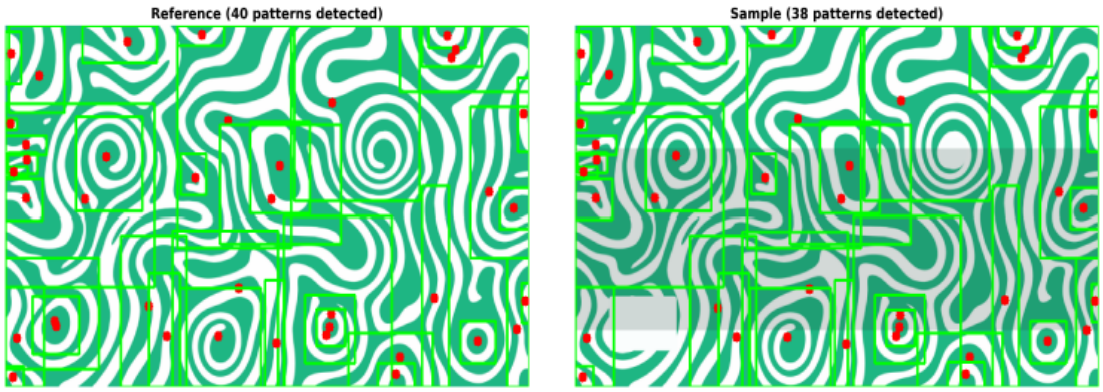

Figure 13: Pattern Count Analysis (Reference and Sample detection maps)

20.1 What This Image Shows

Side-by-side visualization of detected repeating patterns in both Reference and Sample images.

20.2 Detection Method

Using connected components analysis:

1. Convert to grayscale
2. Apply Otsu thresholding
3. Label connected regions
4. Filter by area ($A_{min} \leq A \leq A_{max}$)

20.3 How to Read This Image

- **Green rectangles:** Bounding boxes of detected patterns
- **Red dots:** Centroids of patterns
- **Number at top:** Total patterns detected

20.4 Interpretation Guide

Observation	Interpretation
Same count in both	Pattern repetition consistent
Sample has fewer	Missing patterns (print dropout)
Sample has more	Extra patterns (contamination, doubles)
Different positions	Pattern alignment issue
Different sizes	Pattern scale variation
Clustered vs spread	Distribution uniformity difference

21 IMAGE 14: Pattern Count Comparison

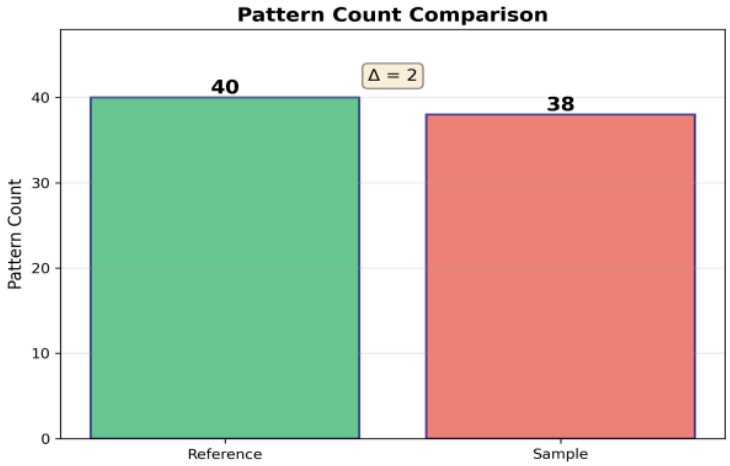

Figure 14: Pattern Count Comparison Bar Chart

21.1 What This Image Shows

Bar chart directly comparing the number of detected patterns in Reference vs Sample.

21.2 How to Read This Chart

- **Green bar:** Reference pattern count
- **Red bar:** Sample pattern count
- **Number on bars:** Exact count
- **Δ value:** Absolute difference

21.3 Status Determination

$$\text{Count Difference} = |\text{Ref Count} - \text{Sample Count}| \tag{47}$$

Status	Criteria
PASS	Difference $\leq$ tolerance (default: 5)
CONDITIONAL	Difference $\leq 2 \times$ tolerance
FAIL	Difference $> 2 \times$ tolerance

22 IMAGE 15: Blob Detection Results

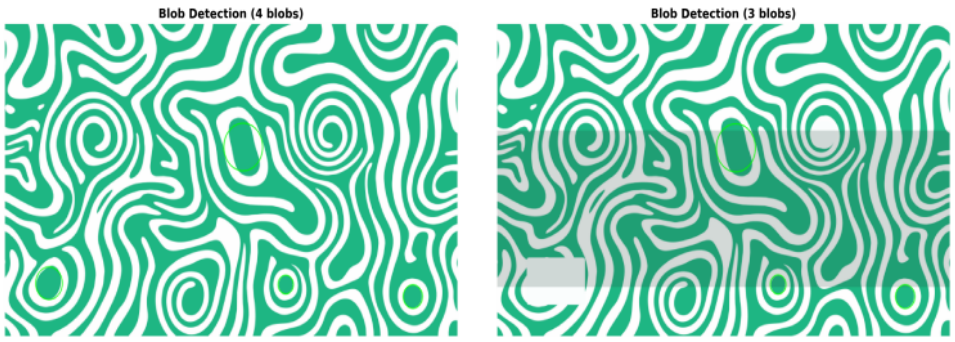

Figure 15: Blob Detection Results

22.1 What This Image Shows

Patterns detected using SimpleBlobDetector, which finds circular or blob-like features.

22.2 Detection Parameters

- **Filter by Area:** A_{min} to A_{max}
- **Filter by Circularity:** ≥ 0.5 (how round)
- **Filter by Convexity:** ≥ 0.8 (how convex)

22.3 How to Read This Image

- **Green circles:** Detected blobs
- **Circle size:** Proportional to blob size
- **Number shown:** Total blob count

22.4 Metrics Provided

Metric	Meaning
Blob Count	Number of detected blobs
Mean Area	Average blob size (px^2)
Area CV%	Size variation ($100 \times \sigma/\mu$)
Mean Size	Average diameter

23 IMAGE 16: Keypoint Matching Analysis

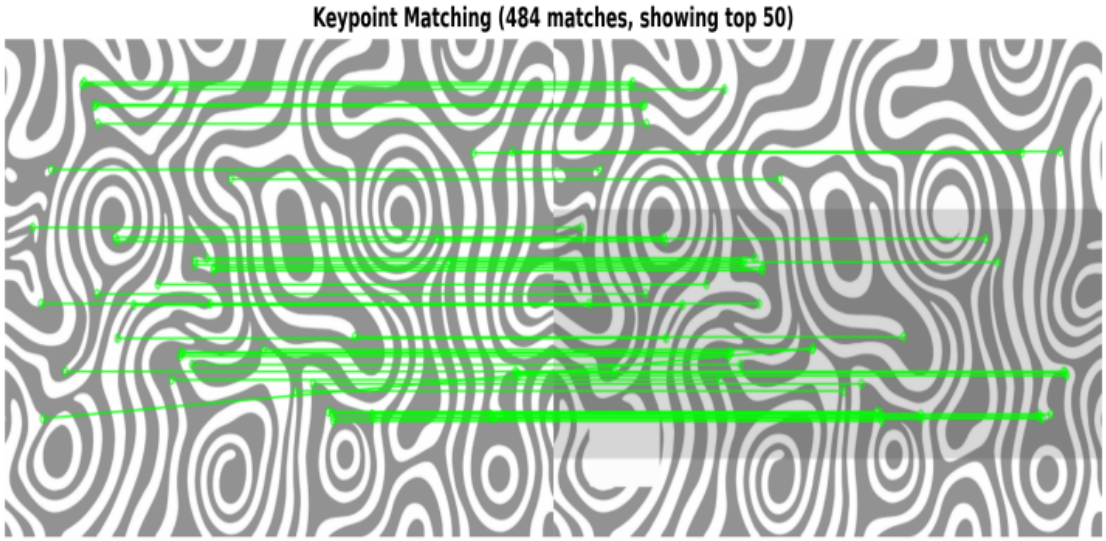

Figure 16: Keypoint Matching Between Reference and Sample

23.1 What This Image Shows

Visualization of matched keypoints (distinctive features) between Reference and Sample images.

23.2 Detection Methods

The system supports:

- **ORB:** Oriented FAST and Rotated BRIEF (default, patent-free)
- **SIFT:** Scale-Invariant Feature Transform
- **AKAZE:** Accelerated-KAZE

23.3 How to Read This Image

- **Left image:** Reference with keypoints
- **Right image:** Sample with keypoints
- **Green lines:** Matching keypoint pairs
- **Red dots:** Keypoints

23.4 Metrics Provided

Metric	Meaning
Keypoints (Reference)	Features found in reference
Keypoints (Sample)	Features found in sample
Good Matches	Pairs passing Lowe's ratio test
Match Ratio	Good matches / Reference keypoints
Matching Score	Good matches / max(ref, sample) $\times$ 100
Inliers (RANSAC)	Matches consistent with transformation

23.5 Interpretation Guide

Observation	Interpretation
Many green lines	Good pattern correspondence
Few green lines	Poor match (different patterns)
Lines mostly parallel	Patterns aligned correctly
Lines crossing	Misalignment or different scale
High inlier count	Consistent geometric transformation

24 IMAGE 17: Auto-correlation Analysis

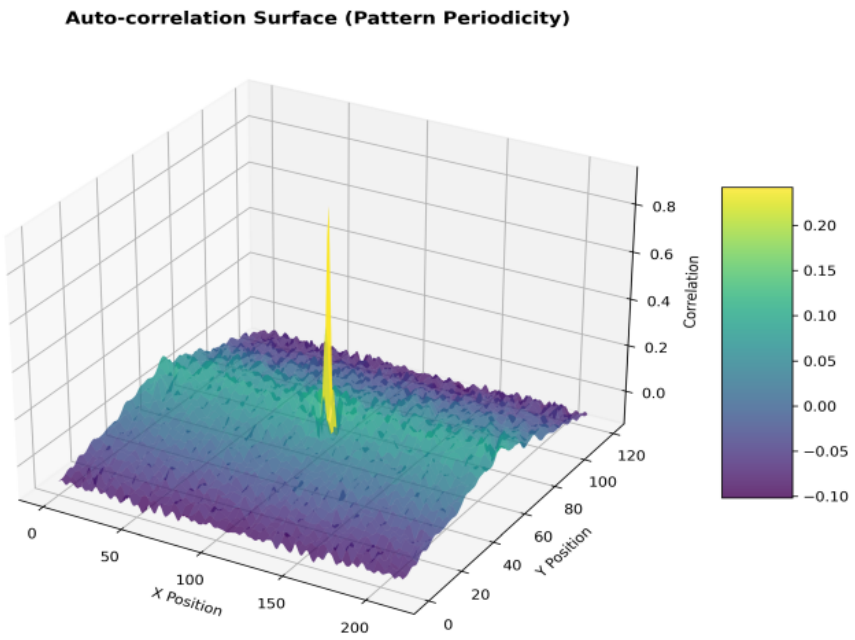

Figure 17: Auto-correlation Surface (3D Plot)

24.1 What This Image Shows

3D surface plot of the 2D auto-correlation function, revealing pattern periodicity.

24.2 How It's Calculated

$$R(u,v) = \text{IFFT2D}\left(|F(x,y)|^2\right) \tag{48}$$

Where F is the Fourier transform of the grayscale image.

24.3 How to Read This Image

- **Central peak:** Always highest (self-correlation at lag 0)
- **Secondary peaks:** Indicate periodicity
- **Peak spacing:** Pattern repeat distance
- **Peak height:** Strength of periodicity

24.4 Interpretation Guide

Pattern	Interpretation
Only central peak	No periodic pattern
Regular grid of peaks	Regular repeating pattern
Peaks along one axis	Striped pattern
Peaks at angles	Diagonal periodicity
Irregular peaks	Quasi-periodic or noisy pattern
Sharp peaks	Well-defined pattern
Broad peaks	Less precise periodicity

24.5 Metrics Provided

Metric	Meaning
Periodicity Score	Mean peak value × 100 (higher = more periodic)
Pattern Spacing	Average distance to secondary peaks (pixels)
Regularity Score	$100 - \min(100, \sigma_{spacing}/\mu_{spacing} \times 100)$

25 IMAGE 18: Spatial Distribution Analysis

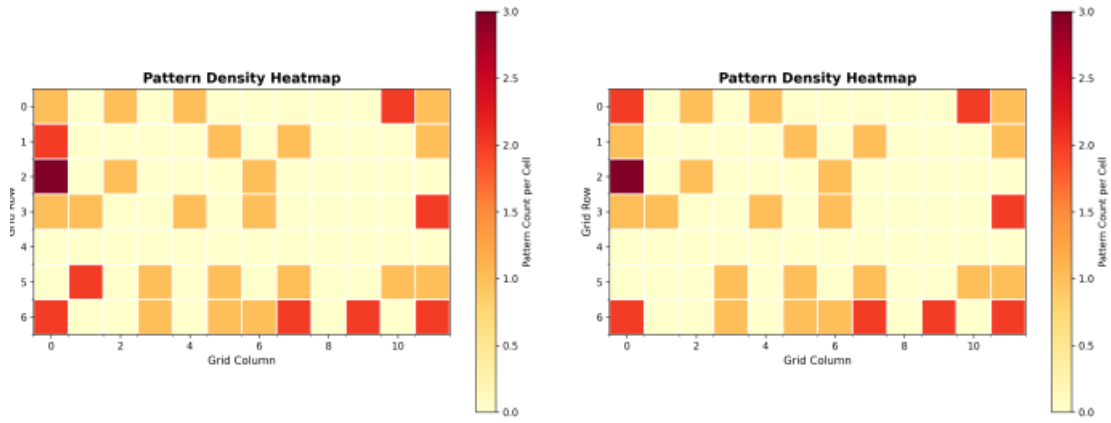

Figure 18: Pattern Density Heatmaps (Reference and Sample)

25.1 What This Image Shows

Grid-based heatmaps showing pattern density across the image area.

25.2 How It's Calculated

1. Divide image into grid cells (default: 50×50 px)
2. Count patterns in each cell
3. Create density heatmap

25.3 How to Read These Heatmaps

- **Color scale:** Yellow-Orange-Red (low to high density)
- **Grid lines:** Cell boundaries
- **Numbers in cells:** Pattern count per cell (if visible)

25.4 Interpretation Guide

Pattern	Interpretation
Uniform color	Even pattern distribution
Patchy appearance	Uneven distribution
Sample darker overall	Fewer patterns in sample
Different hot spots	Pattern drift/misalignment
Edge effects	May indicate cropping issues

25.5 Metrics Provided

Metric	Meaning
Grid Size	Rows × Columns
Mean Density	Average patterns per cell
Density Std Dev	Variation in density
CV%	Coefficient of variation
Uniformity Score	$\max(0, 100 - \text{CV\%})$

26 IMAGE 19: Pattern Integrity Assessment

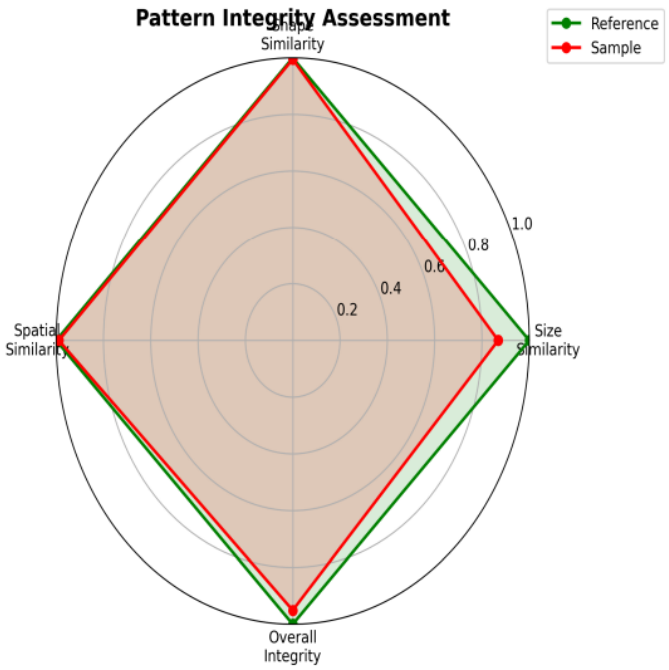

Figure 19: Pattern Integrity Radar Chart

26.1 What This Image Shows

Radar chart comparing multiple aspects of pattern integrity between Reference and Sample.

26.2 Integrity Components

Component	What It Measures
Size Similarity	How similar pattern sizes are
Shape Similarity	How similar pattern shapes are (solidity)
Spatial Similarity	How similar pattern spacing is
Overall Integrity	Average of all three

26.3 How to Read This Chart

- **Green polygon:** Reference (always perfect = 100%)
- **Red polygon:** Sample comparison
- **Each axis:** One integrity component (0-100%)
- **Distance from center:** Score value

26.4 Interpretation Guide

Observation	Interpretation
Red matches green	Perfect pattern reproduction
Red smaller overall	General pattern degradation
Red smaller on Size	Pattern size variation
Red smaller on Shape	Pattern distortion
Red smaller on Spatial	Pattern spacing issues

26.5 Status Thresholds

For each component:

- $\geq 85\%$: PASS
- $70 - 85\%$: CONDITIONAL
- $< 70\%$: FAIL

27 IMAGE 20: Pattern Size Comparison

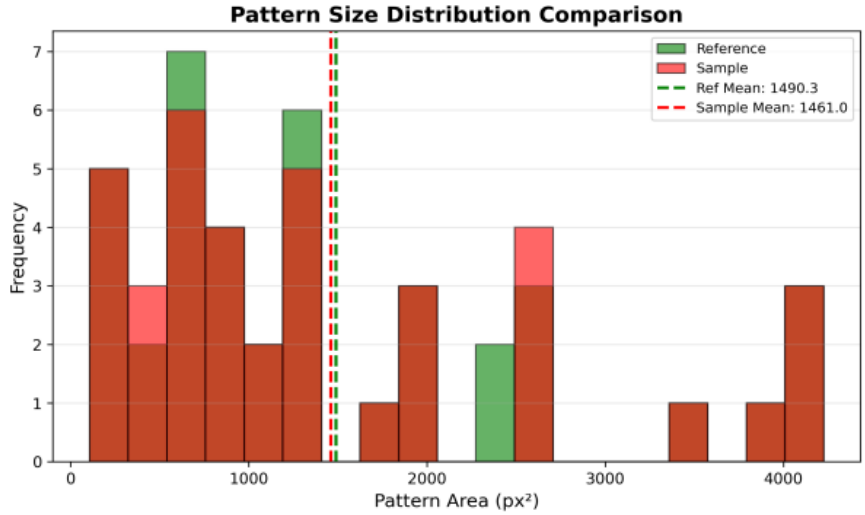

Figure 20: Pattern Size Distribution Histogram

27.1 What This Image Shows

Overlaid histograms comparing the distribution of pattern sizes (areas) in Reference vs Sample.

27.2 How to Read This Chart

- **X-axis:** Pattern area (px^2)
- **Y-axis:** Frequency (count)
- **Green bars/line:** Reference distribution
- **Red bars/line:** Sample distribution
- **Dashed vertical lines:** Mean values

27.3 Interpretation Guide

Pattern	Interpretation
Histograms overlap	Similar pattern sizes
Sample shifted right	Larger patterns in sample
Sample shifted left	Smaller patterns in sample
Sample wider spread	More size variation
Sample narrower	More uniform sizes
Multiple peaks	Different pattern types present

27.4 Key Statistics

The report includes:

- Mean area (Reference vs Sample)
- Standard deviation
- CV% (coefficient of variation)

28 IMAGE 21: Missing/Extra Patterns Catalog

Figure 21: Missing and Extra Patterns Overlay

28.1 What This Image Shows

Visual overlay on the sample image highlighting:

- **Red circles:** Missing patterns (expected but not found)
- **Blue circles:** Extra patterns (found but not expected)

28.2 Detection Method

Using spatial matching with KD-tree:

1. Build spatial tree of reference pattern centroids
2. For each sample pattern, find nearest reference pattern
3. If distance > tolerance: mark as extra
4. Reference patterns with no nearby sample: mark as missing

28.3 How to Read This Image

- **Red circles:** Locations where patterns are missing
- **Blue circles:** Locations of unexpected extra patterns
- **Legend:** Shows counts of each type

28.4 Interpretation Guide

Pattern	Possible Cause
Scattered missing	Random print dropout
Clustered missing	Blocked print head or screen
Row of missing	Line jam or feed issue
Extra patterns scattered	Contamination
Extra patterns clustered	Double strike or ghost print
Edge-only issues	Alignment or masking problem

28.5 Severity Classification

Each missing/extra pattern has severity:

- **High:** Larger than median pattern size
- **Medium:** Smaller than median pattern size

29 IMAGE 22: Metamerism Analysis

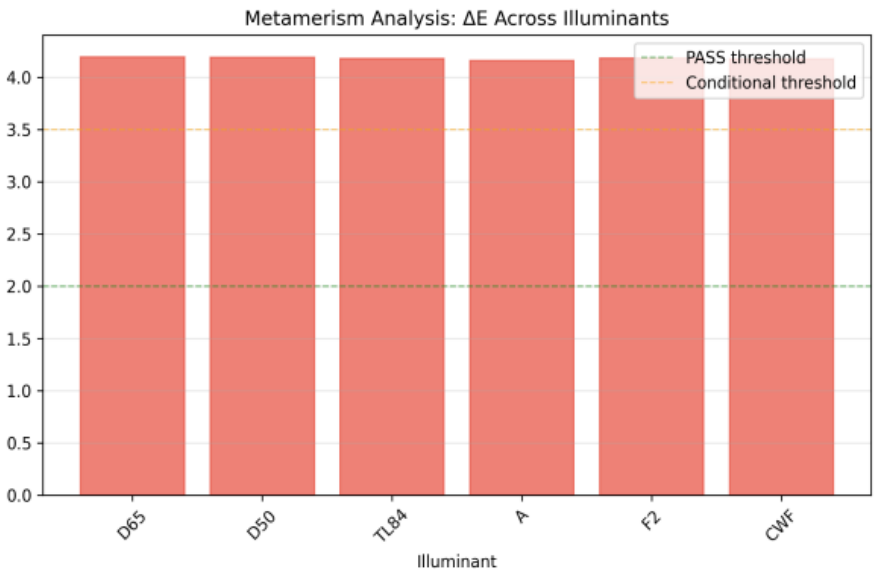

Figure 22: Metamerism Analysis: ΔE Across Illuminants

29.1 What This Image Shows

Bar chart showing ΔE_{2000} under different illuminants to assess metamerism risk.

29.2 What is Metamerism?

Metamerism occurs when two colors appear to match under one light source but not under another. This is critical for:

- Retail environments (daylight vs store lighting)
- Quality control (lab vs production floor)
- Customer expectations (home vs store appearance)

29.3 Illuminants Tested

Illuminant	Represents
D65	Standard daylight (6500K)
D50	Horizon daylight (5000K)
TL84	Store/office fluorescent (3800K)
A	Incandescent/tungsten (2856K)
F2	Cool white fluorescent
CWF	Cool white fluorescent (alternative)

29.4 How to Read This Chart

- **X-axis:** Illuminant type
- **Y-axis:** ΔE_{2000} value
- **Bar colors:**
  - Green: $\Delta E < 2.0$ (PASS)
  - Orange: $2.0 \leq \Delta E < 3.5$ (CONDITIONAL)
  - Red: $\Delta E \geq 3.5$ (FAIL)
- **Dashed lines:** Threshold markers

29.5 Interpretation Guide

Observation	Interpretation
All bars green	Low metamerism risk
One bar higher	Potential issue under that light
TL84/A much higher	Store/home appearance may differ
Increasing trend	Systematic spectral mismatch
All bars high	Fundamental color mismatch

29.6 Key Output

Worst-case metamerism: The illuminant with highest ΔE is reported, as this represents the most critical viewing condition.

30 Quality Assessment Tables

30.1 Lab* Threshold Assessment

Parameter	Default Threshold	Interpretation
$\lvert\Delta L^*\rvert$	≤ 1.0	Lightness shift
$\lvert\Delta a^*\rvert$	≤ 1.0	Red-Green shift
$\lvert\Delta b^*\rvert$	≤ 1.0	Yellow-Blue shift
Overall Magnitude	≤ 2.0	$\sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$

30.2 Recommendations Lookup

Issue	Recommended Action
$\|\Delta L^*\| >$ threshold	Adjust dye concentration / dwell time
$\|\Delta a^*\| >$ threshold	Tune dye formulation on a^* axis
$\|\Delta b^*\| >$ threshold	Modify temperature/pH to counter b^* deviation
Overall magnitude exceeded	Review process parameters; consider re-processing

31 Conclusion Section

31.1 Final Decision Categories

Decision	Recommended Actions
ACCEPT	Sample matches reference. Maintain parameters. Regular monitoring.
CONDITIONAL ACCEPT	Near limits. Fine-tune process. Monitor closely.
REJECT	Significant deviation. Review dyeing parameters, chemical concentrations. Consider re-processing.

32 Configurable Parameters Reference

32.1 Color Thresholds

Parameter	Default	Description
ΔE Threshold (PASS)	2.0	Max ΔE for PASS
ΔE Conditional	3.5	Max ΔE for CONDITIONAL
Lab L^* Threshold	1.0	Max lightness deviation
Lab a^*/b^* Threshold	1.0	Max chromatic deviation
Lab Overall Threshold	2.0	Max total Lab magnitude

32.2 Pattern Thresholds

Parameter	Default	Description
SSIM PASS	0.95	Min SSIM for PASS
SSIM Conditional	0.90	Min SSIM for CONDITIONAL
Pattern Count Tolerance	5	Max pattern count difference

32.3 Scoring Multipliers

Parameter	Default	Description
Color Score Multiplier	20.0	Penalty per ΔE unit
Uniformity Std Multiplier	10.0	Penalty for non-uniformity
Color Score Minimum	70.0	Min score for PASS
Pattern Score Minimum	90.0	Min score for PASS
Overall Score Minimum	70.0	Min overall for CONDITIONAL

32.4 Advanced Texture Parameters

Parameter	Default	Description
FFT Peaks	5	Number of peaks to detect
Gabor Frequencies	0.1, 0.2, 0.3	Spatial frequencies
Gabor Orientations	8	Number of angles
GLCM Distances	1, 3, 5	Pixel offsets
GLCM Angles	0°, 45°, 90°, 135°	Directions
LBP Points (P)	24	Neighbors in ring
LBP Radius (R)	3	Ring radius
Wavelet Type	db4	Daubechies-4
Wavelet Levels	3	Decomposition depth

33 Quick Reference Checklist

33.1 For Technicians: Report Review Checklist

1. **Executive Summary**: Check overall decision (ACCEPT/CONDITIONAL/REJECT)
2. **Color Score**: Should be ≥ 70
3. ΔE_{2000} **Mean**: Should be < 2.0 for PASS
4. **SSIM**: Should be $> 95\%$ for PASS
5. **Uniformity Index**: Should be ≥ 85
6. ΔE **Heatmap**: Check for localized hot spots
7. **Pattern Count**: Difference should be within tolerance
8. **Integrity Score**: Should be $\geq 85\%$
9. **Metamerism**: Check for high bars under key illuminants

33.2 For Operators: Key Metrics to Monitor

Metric	Target	Action if Failed
ΔE_{2000}	< 2.0	Adjust dye formulation
ΔL^*	< 1.0	Adjust concentration/time
SSIM	$> 95\%$	Check pattern alignment
Metamerism	< 2.0	Review dye chemistry
Pattern Count Diff	≤ 5	Check printing/dyeing process

34 Appendix: Formulas Quick Reference

$$\text{Color Score} = \max(0, 100 - \bar{\Delta E}_{76} \times 20) \tag{49}$$

$$\text{Pattern Score} = \text{SSIM} \times 100 \tag{50}$$

$$\text{Overall Score} = \frac{\text{Color Score} + \text{Pattern Score}}{2} \tag{51}$$

$$\text{Uniformity Index} = \max(0, 100 - \sigma_{\Delta E} \times 10) \tag{52}$$

$$\text{Metamerism Index} = 10 \times \sigma(\Delta E_{D65}, \Delta E_{TL84}, \Delta E_A) \tag{53}$$

$$\text{Edge Definition} = \min(100, \text{Var}(\nabla^2 I)/50) \tag{54}$$

$$\text{Integrity Score} = \frac{\text{Size Sim} + \text{Shape Sim} + \text{Spatial Sim}}{3} \tag{55}$$

35 Image Summary Table

#	**Image Name**	**Key Thing to Check**	**Good Result Looks Like**
1	Spectral Proxy	Lines alignment	Overlapping curves
2	Visual Difference	Hot spots in heatmap	Uniform dark color
3	Lab* Viz	Cloud overlap	Green/red clouds overlap
4	RGB Histograms	Peak alignment	Similar peak positions
5	FFT Spectrum	Peak pattern	Symmetric peaks
6	Gabor Montage	Bright cells	Same cells bright in both
7	Gabor Energy	Peak orientation	Same dominant angle
8	GLCM Radar	Shape match	Polygons overlap
9	LBP	Histogram overlap	Bars align
10	Wavelet	Bar heights	Similar heights
11	Line Angle	Peak position	Same dominant angle
12	Defect Map	Bright spots	Mostly dark
13	Pattern Detection	Count match	Similar counts
14	Pattern Count	Bar heights	Equal or close
15	Blob Detection	Circle count	Similar counts
16	Keypoint Match	Green lines	Many connecting lines
17	Autocorrelation	Peak pattern	Similar peak structure
18	Spatial Dist	Color pattern	Uniform color
19	Integrity	Polygon size	Red matches green
20	Pattern Size	Histogram overlap	Overlapping distributions
21	Missing/Extra	Circle count	No circles (none missing/extra)
22	Metamerism	Bar colors	All green bars