Measuring Canvas Density from Images

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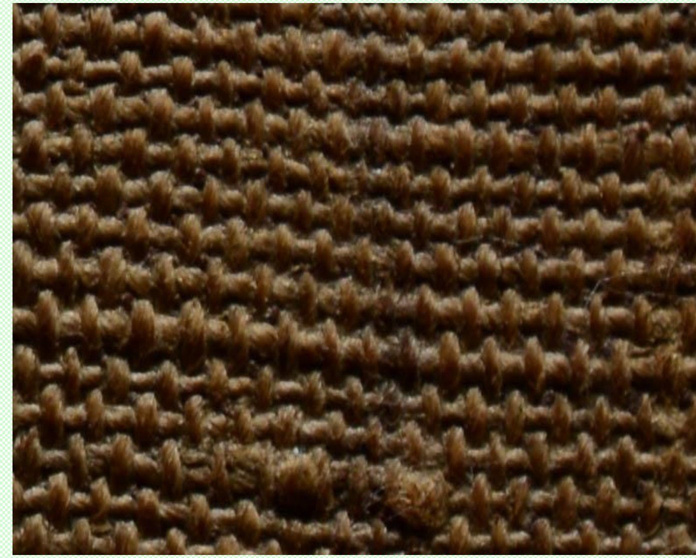
Problem Formulation



Canvas of a painting

The problem: It is necessary to measure warp and weft thread density.

Thread counting from images is used to determine characteristics used by art historians for dating works of art (Mazina A. Y., 2014; Ivanova E.Yu., 2004; Kosolapov A. I., 2010).

Conventional Techniques

1. Automated algorithms for calculating canvas characteristics from x-ray images (Johnson, C. R., et al., 2008 - 2013).
2. Algorithms for calculating canvas characteristics from high-quality terahertz images (van der Maaten L., et al., 2011–2014).
3. Measuring thread densities of woven fabric from microscopic photographs, obtained when the fabric sample is illuminated by a light transmitted source (Pan R.W. et al. 2015).

Drawbacks of the conventional techniques:

- x-ray images cannot be used if white lead is present in the paint layer of paintings;
- terahertz equipment is not widely used in museums;
- paint layer blocks transmitted light.

Our approach:

Acquire canvas images in raking light. This way of acquiring images allows to emphasize canvas texture in the specified direction.

Canvas Image Features

Canvas features:

- uneven canvas tension causes thread curvature;
- varying thread thickness;
- canvas damages;
- ground infiltration;
- pollution.

Image acquisition

Canvas images are fixed by 24 MP CCD camera NIKON 86 D 7100.

Lens: NIKON AF-S Micro NIKKOR 40mm 1 : 2, 8 G.

Light: LOWEL TOTA-LIGHT T1−10, lamp: EMF Q800T34 MIH 800W 240V R7s.

Distance: 25 cm.

Light angle: 10-30 degrees.

Image size: 6000×4000 pixels;

Model of canvas image in raking light

Model of canvas image :

$$I(\mathbf{x}) = I_0 + a \cdot \sin(2\pi \mathbf{k}^T \mathbf{x} - \varphi) + n(\mathbf{x}),$$

where $I(\mathbf{x})$ is a gray level value at image point $\mathbf{x}$ with coordinates (x, y) ; I_0 is a gray level shift; a is an amplitude of gray level; $\mathbf{k} = (k_1, k_2)^T$ is a vector of wave numbers; φ is a phase value; $n(\mathbf{x})$ is a periodic function modeling thread weave.

Model of canvas image in raking light when $n(\mathbf{x}) = 0.$

Algorithms for Counting Canvas Threads

We used three algorithms for counting threads.

1. Two modifications of method by Pan R.W. et al. (2015):
   - based on Otsu thresholding technique;
   - based on Niblack thresholding technique.
2. Algorithm based on detection of image ridges.

Algorithms Based on Filtering in Fourier Domain

1. Filtering canvas image: $$I_F(\mathbf{x}) = \mathcal{F}^{-1}\{\mathcal{F}\{I(\mathbf{x})\}I_M(\mathbf{x})\},$$

   where $I_F(\mathbf{x})$ is filtered image; $I_M(\mathbf{x})$ is filter mask.

2. Thresholding

$$I_T(\mathbf{x}) = \begin{cases} 255, \ if \ \ I_F(\mathbf{x}) \geq T^* \\ 0, \quad if \ \ I_F(\mathbf{x}) < T^* \end{cases},$$

   a) Otsu's method: $$\sigma_B^2(T^*) = \max_{0 \leq T_O \leq 255} \sigma_B^2(T_O), \quad \sigma_B^2 = \frac{(m_G P_1 - m(T_O))^2}{P_1(1-P_1)},$$

$$m(T_O) = \sum_{i=0}^{T_O} ip_i, \ m_G = \sum_{i=0}^{255} ip_i, \ \ P_1 = \sum_{i=0}^{T_O} p_i.$$

   b) Niblack's method:

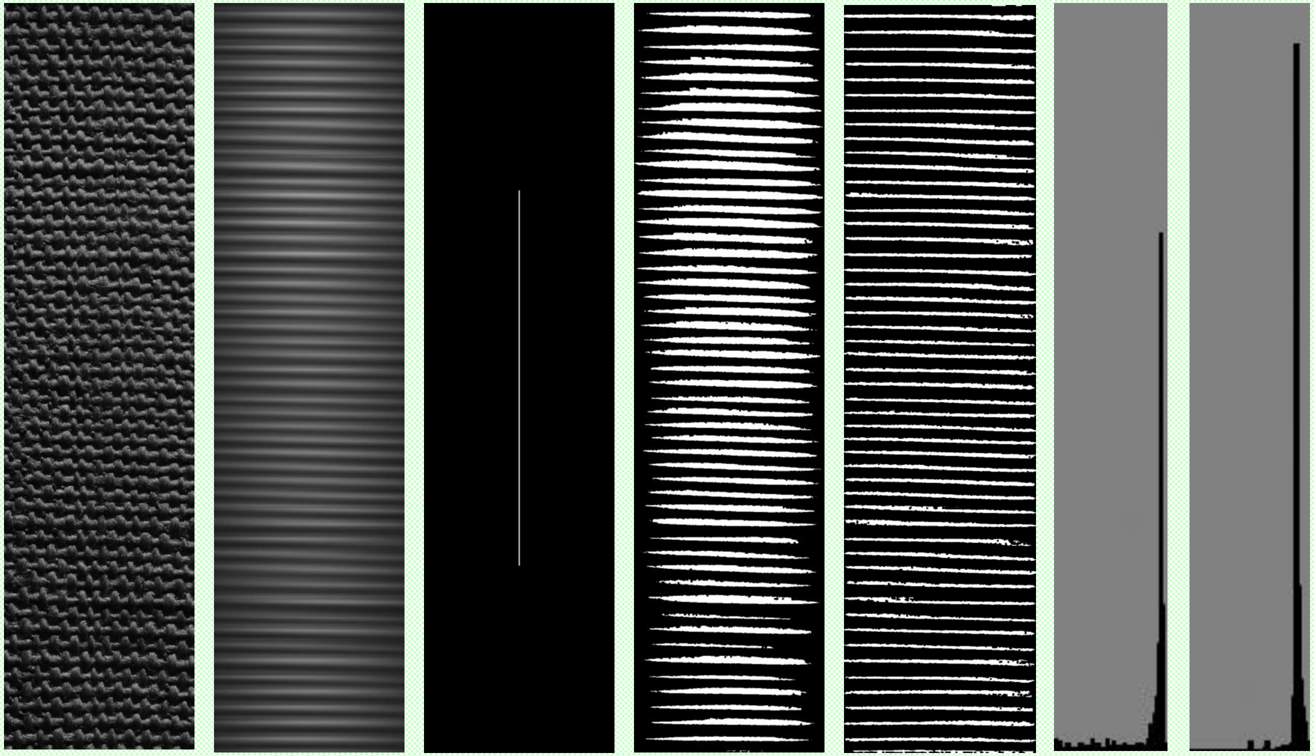
$$T^* = m + k_N \sigma_N,$$

   where m is grayscale mean value in a window W.

3. Erosion: $$I_{eroded}(\mathbf{x}) = \varepsilon_{SE}(I_T(\mathbf{x})).$$

4. Counting binary objects in $I_{eroded}(\mathbf{x})$ columns.

Algorithms Based on Filtering in Fourier Domain



Steps of the algorithms based on filtering in Fourier domain

Algorithms Based on Detection of Image Ridges

Image description:

$$I(\mathbf{x}) \in C^2(R^2, R),\ DI \neq 0,\ \mathbf{x} = (x, y)^T,\ DI = (I_x, I_y)^T.$$

Let $N = DI/|DI|,\ T = DI^{\perp}/|DI|,\ DI^{\perp} = (-I_y, I_x)^T.$

Expression based on Hessian $D^2 I$:

$$-\frac{1}{|DI|}\begin{bmatrix} N^T D^2 I N & N^T D^2 I T \\ T^T D^2 I N & T^T D^2 I T \end{bmatrix} = \begin{bmatrix} g & \mu \\ \mu & k \end{bmatrix},$$

where $g = -N^T (D^2 I/|DI|) N;\ \mu = -T^T (D^2 I/|DI|) N,\ k = -T^T D^2 I T.$

At points of ridges of $I(\mathbf{x})$, the conditions are taking place (*Eberly D. 1996*):

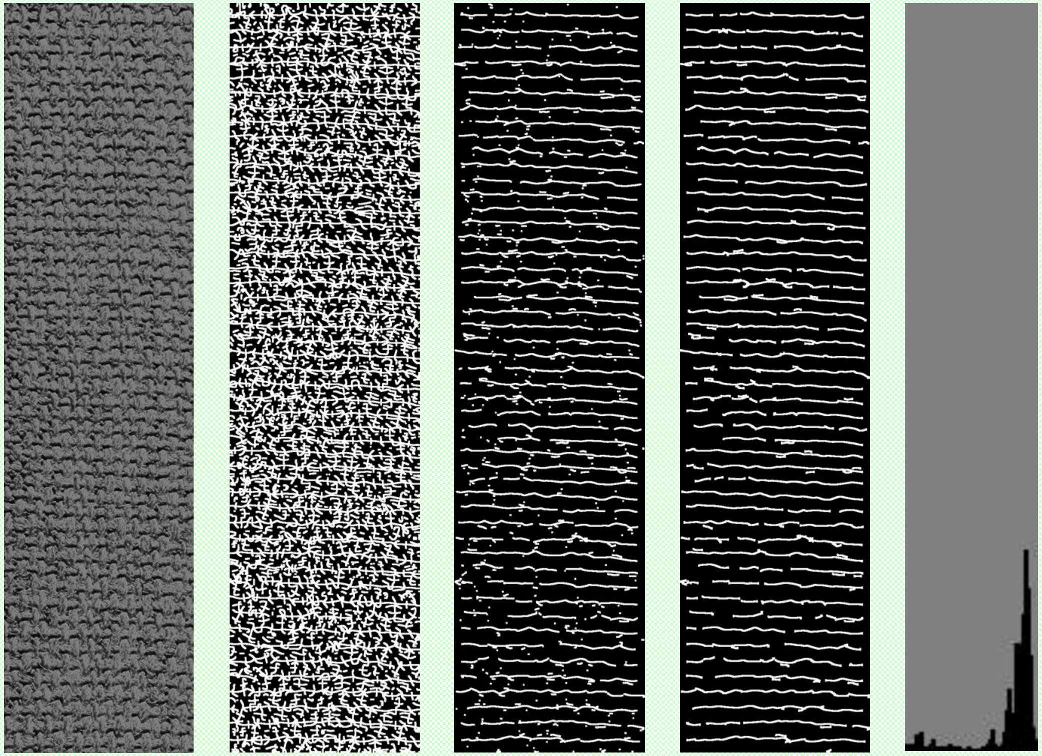
$$\mu = 0,\ k > \max\{0, g\}.$$

Algorithms Based on Detection of Image Ridges

Algoritm

1. Correction of uneven illumination based on morphological closing.
2. Gaussian blurring.
3. Detection of ridges.
4. Pruning – 20 iterations.
5. Erosion with linear structuring element.
6. Dilation with square structuring element.
7. Removing small connected components.
8. Counting binary objects in image columns.

Algorithm Based on Detection of Image Ridges



Steps of the algorithms based on image ridges

Computing Experiment

Tasks of the experiment: to estimate workability of image acquisition technique and thread counting algorithms.

1. 30 sample images are taken from 5 paintings by Russian artist of 18 century, 3 samples from 1 canvas image.
2. Images are fixed in raking light at angles from 10 to 30 degrees.
3. Canvas sample size

   width: from 0.7 to 1.7 cm;

   height: from 4.8 to 8.7 cm.
4. Sample image size

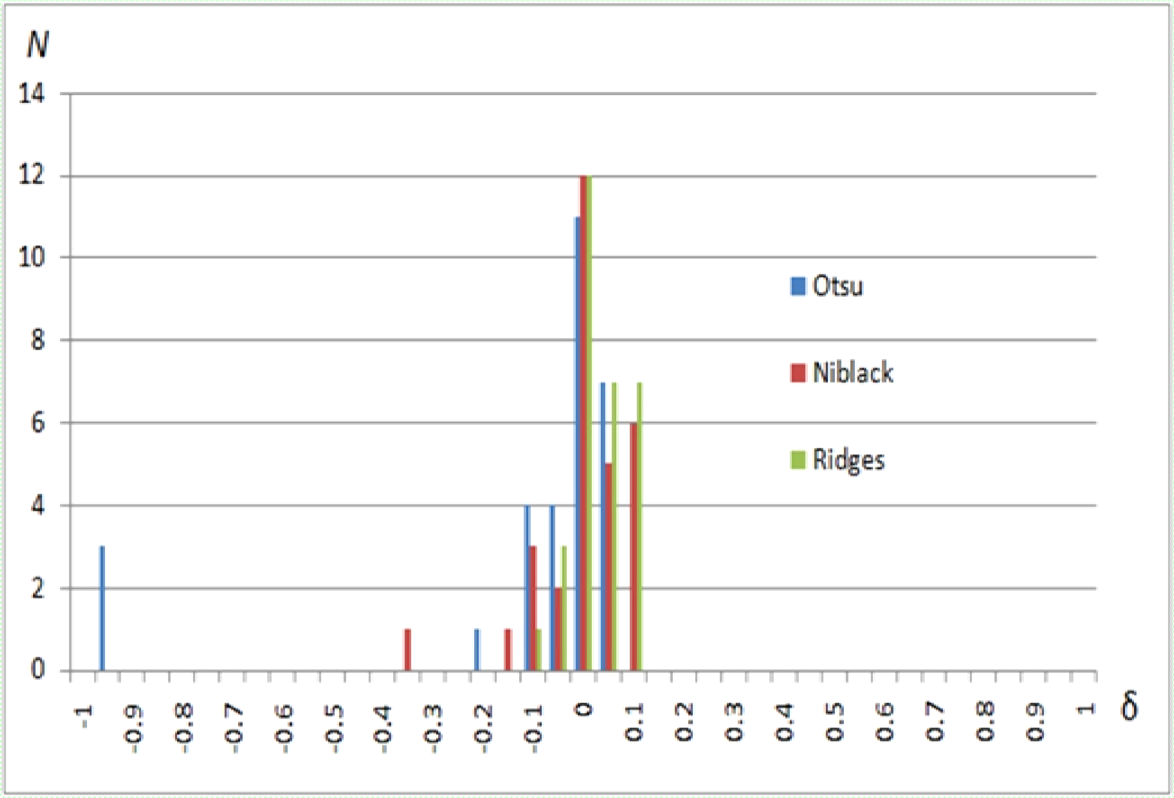
   width: from 481 to 705 pixels;

   height: from 2085 to 3521 pixels.
5. All sample images contain from 50 to 110 threads.

Results of the Experiment

Processing time for 529 by 2777 pixels image:

Algorithm	Time(s)
Otsu-based	1.83
Niblack-based	37.74
Ridges-based	48.29



Error: $$\delta = \frac{N_a - N_e}{N_e}$$

Algorithm	Percentage of samples giving error within 1 thread/cm
Otsu-based	70%
Niblack-based	83%
Ridges-based	97%

CONCLUSIONS

1. The problem of painting thread counting from images was considered.
2. The peculiarity of this research is acquiring canvas images in raking light. This way of acquiring images allowed to emphasize the canvas texture in the specified direction.
3. Two modifications of known algorithm based on a filtering in the Fourier domain and thresholding, and the new algorithm based on localizing grayscale image ridges were proposed.
4. Counting of threads was performed over all rows / columns of the image matrix, and a histogram of measurements was constructed. The use of histograms allowed to reduce inaccuracy produced by the artifacts obtained from image processing operations.
5. Computing experiment on the study of canvases of five portraits by Russian artists of the 18th century was carried out.
6. The researched algorithms provide the accuracy of measuring the canvas density from within one thread per centimeter for 70−97 percents of the sample images.