Algorithms for Old Master Painting Canvas Thread Counting from X-rays

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Image processing in support of painting analysis

» Museums have embraced digital imaging.
» Facilitates interaction between image processors and art historians for such tasks as:
  - image acquisition, storage, and database search.
  - image analysis that supports the art historian's mission of painting analysis
» Art historical painting analysis and signal processing are disparate fields, presenting a daunting challenge to cross-disciplinary collaboration.
» One approach: provide signal processing tools that assist or automate procedures art historians currently conduct.

Thread count information

» Used by art historians in support of claim that canvases on which different paintings are painted are from same bolt.
» Can justify conclusions that paintings are from the same artist, or a collaborative effort (e.g. van Gogh and Gauguin).
» Has been used as a major forensic tool in attribution efforts (e.g. the decades-long Rembrandt Research Project).
» Often cannot be obtained from front of canvas
  ? front is covered by paint.
» Often cannot be obtained from back of canvas
  ? additional canvas glued to back for strengthening
» In such cases, must count threads from x-rays.

Current manual thread counting procedure

» Cumbersome, involves estimating the (possibly fractional) number of threads along a 2cm line segment under a microscope.
» Done as a specific question arises, not as standard method of documentation.
» Difficult to document location from which thread counts were obtained.
» Not repeatable.

Canvas weave model

» Define horizontal, vertical, and composite weave as:

$$\begin{aligned} h(x,y) &= \sin(2\pi f_h x)\,\mathrm{square}_\delta(2\pi f_v y) \\ v(x,y) &= -\sin(2\pi f_v y)\,\mathrm{square}_\delta(2\pi f_h x) \\ f(x,y) &= \max(h(x,y), v(x,y)) \end{aligned}$$

where $\mathrm{square}_\delta(z) = \begin{cases} 0 & |\sin(z)| < \delta \\ \mathrm{sign}(\sin(z)) & \text{otherwise} \end{cases}$

» Vertical projection:

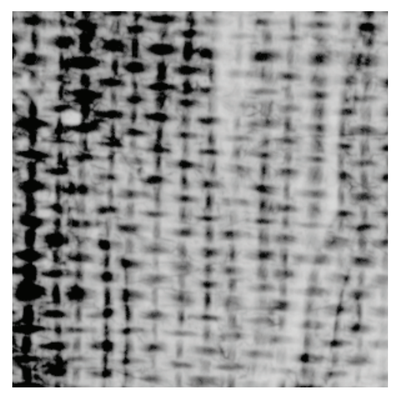
$$\begin{aligned} p(y) &= \int f(x,y)dx \\ &= \int_{h(x,y)>0)} \sin(2\pi f_h x)\,\mathrm{square}(2\pi f_v y)dx \\ &\quad + \int_{v(x,y)>0} -\sin(2\pi f_v y)\,\mathrm{square}(2\pi f_h x)dx \\ &= c_v + b_v|\sin(2\pi f_v y)| \end{aligned}$$

» Projection contains sinusoidal component.

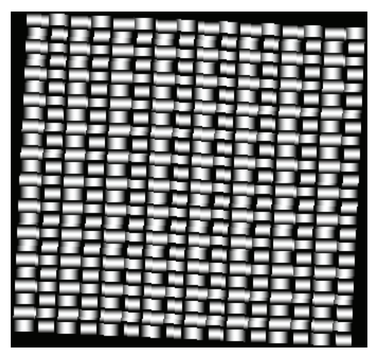
» Suggests use of Radon Transform (for derotation) and Fourier Transform (for estimating period).

» Model permits consideration of three non-idealities:
  1. Varying thread thickness.
  2. Gaps between threads.
  3. Rotated weaves.

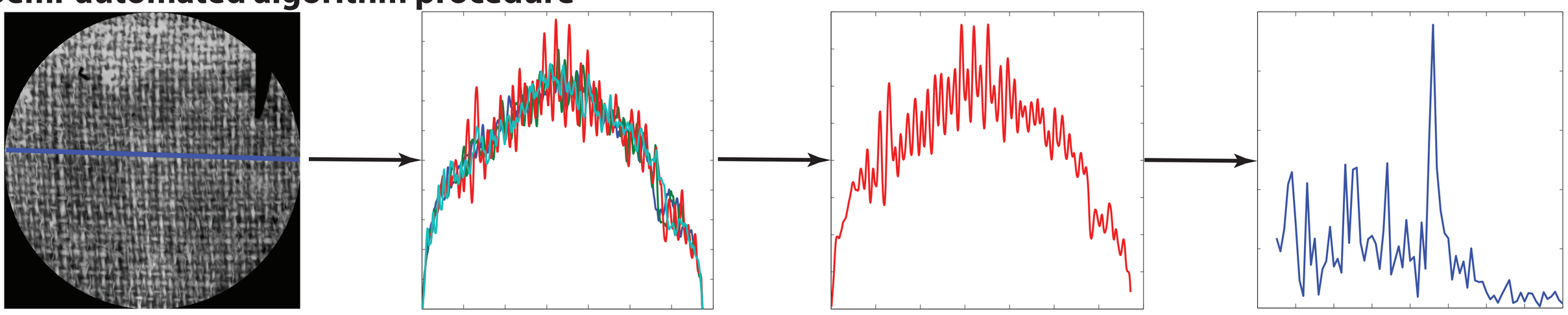
van Gogh's "The Sheep-Shearer" and its 2-D Fourier Transform



Model-generated examples



Semi-automated algorithm procedure



extract circle along line segment

take Radon transform at various rotation angles

choose angle with max variance, then LPF result

take Fourier Transform and choose peak

Results/Conclusion

» Dataset of 20 paintings, x-rays scanned at 600 dpi grayscale.
» Cornell undergraduates manually (and doubly) counted threads over ~1000 2cm swatches.
» Algorithm performance within ±0.5 threads/cm 84% of time, ±1 thread per centimeter 95%.
» As accurate as human, and repeatable.