Frequency Analysis for Art Forensics

By:
Jash GUO

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C O N N E X I O N S

Rice University, Houston, Texas

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Chapter 1

The Team[1]

1.1 The Team

Students

Lucia Sun: ls4@rice.edu[2]

"露露" developed most Matlab codes for the project. Her GPA is greater than 4.0...

[1]This content is available online at <http://cnx.org/content/m18949/1.3/>.
[2]ls4@rice.edu

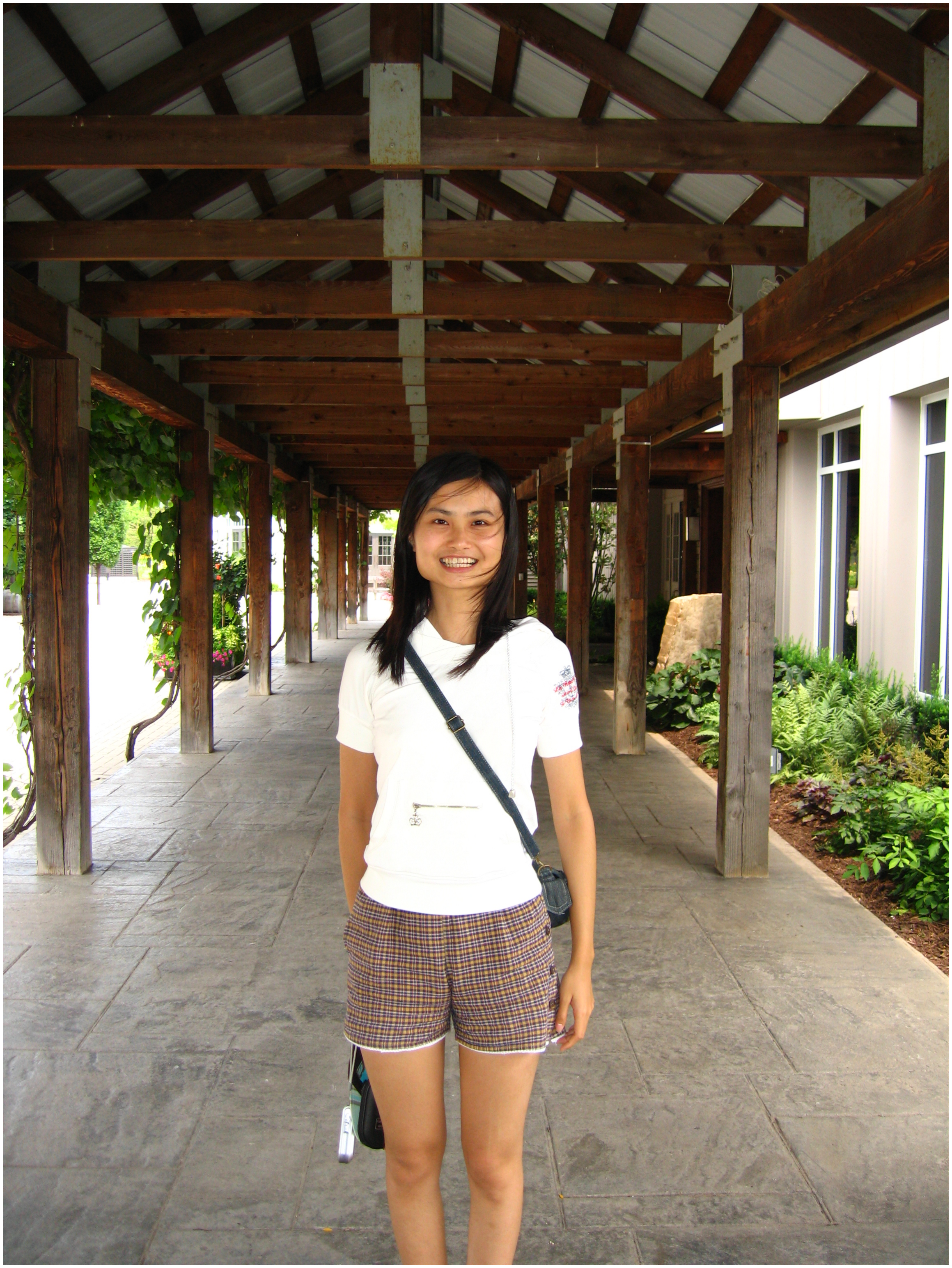


Figure 1.1

Zeting Liu: zbl1@rice.edu[3]

"汀汀" is our poster master. He is an exchange student from a Hong Kong university. Oops, I always forget its name, should be something like HKUST (Hong Kong University of Science and Technology). He is also the CEO of a brilliant website http://www.boliance.com[4] /.

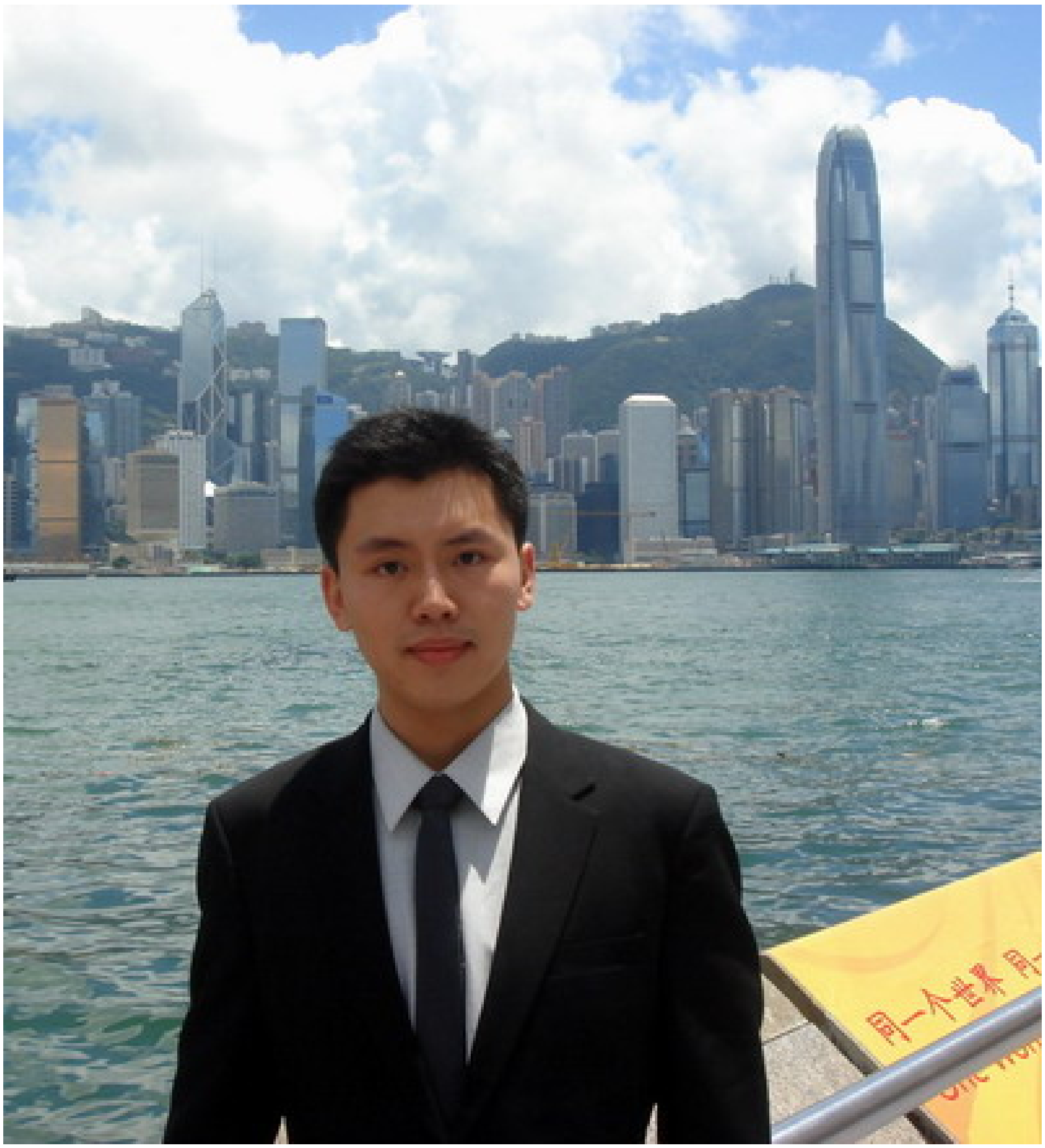


Figure 1.2

[3]zbl1@rice.edu
[4]http://www.boliance.com/

Xiang Guo (Jash): xg1@rice.edu[5]

"享享" Jash did a lot of things including bringing in snacks and treating the team for a buffet dinner. The most important thing he learned in 301 is “Totally!”

Figure 1.3

Mentor

Professor Don H. Johnson: dhj@rice.edu[6]

He is the BIG Guy in DSP. You know what I mean...

[5] xg1@rice.edu
[6] dhj@rice.edu

Figure 1.4

Chapter 2

Introduction[1]

2.1 Abstract

A canvas can be characterized by the vertical and horizontal weave densities while the actual painting serves as an additive signal that only distracts from the thread-counting process. The thread counting algorithm and the spectral techniques we employ in our project can analyze weave density for entire paintings with an accuracy comparable to human measurements more efficiently.

2.2 Motivation

Van Gogh Museum of Amsterdam has a collection of artist's works and is looking for a more advanced analysis for sequencing paintings in addition to the traditional manual methods. Our whole-painting analysis shows that frequency distributions should match if two paintings are from the same canvas roll. This could better support the forensic evidence quantitatively when comparing two paintings.

2.3 Approach

2.3.1 Current Approach

Human measurement – weave threads are manually counted and compared. This approach is inefficient and may not be accurate.

2.3.2 Our New Approach

Use thread counting algorithm and spectral techniques to analyze weave density for entire paintings. Frequency distributions of weave densities should match if two paintings are from same canvas roll.

[1]This content is available online at <http://cnx.org/content/m18943/1.1/>.

Chapter 3

Background[1]

3.1 Warp and Weft

Warp – the vertical threads mounted in a loom. Warps are usually well aligned with a fairly uniform spacing.

Weft – the horizontal threads mounted in a loom. Wefts are usually threaded back and forth through the warp in an interlaced fashion. Therefore the weft shows more variability than the warp.

3.2 Vertical vs. Horizontal

An artist may orient the canvas on the stretcher in whatever way once he or she cuts a piece of canvas fro a painting. But we could expect the thread count having the narrower distribution to be the warp direction.

In our model, the vertical threads create oscillations of x-ray intensity in the x direction, which leads to a horizontal frequency component. The similar idea applies to the horizontal threads and the vertical frequency.

3.3 Canvas Texture Modeling

Canvas texture can be modeled as a sum of two sinusoids having nearly orthogonal spatial frequencies.

$c(x) = p(x) + A/2 * [(2 + ahsin\ (2\pi fh*x + \theta h) + avsin(2\pi fv*x + \theta v)]$

The quantity c(x) is the canvas x-ray image that depends on the 2D spatial variable x; p(x) represents the artist's contribution (the painting) to the x-ray. The constants A, ah and av determine the average intensity and the amplitudes of the horizontal and vertical weave. fv and fh are the vector frequencies corresponding to the vertical and horizontal thread counts, respectively.

3.4 X-Ray Image

Our project uses X-ray images of a painting as the raw data.

The thread used to make a canvas is transparent to x-rays. Fortunately, artists usually prepared their canvases with a white undercoat to smooth the surface. The small variations in undercoat thickness filling the valleys of the canvas weave lead to variations in x-ray opacity that can be measured. The greater the radiographic-absorbing paint thickness along the bean, the greater the opacity, meaning that x-ray image intensity variations correspond to paint thickness variations.

[1] This content is available online at <http://cnx.org/content/m18945/1.1/>.

Figure 2 is the X-ray image of Figure 1- van Gogh's **Portrait of an Old Man with a Beard** (F205/JH971).

Figure 3.1

Figure 3.2

3.5 Weave Density

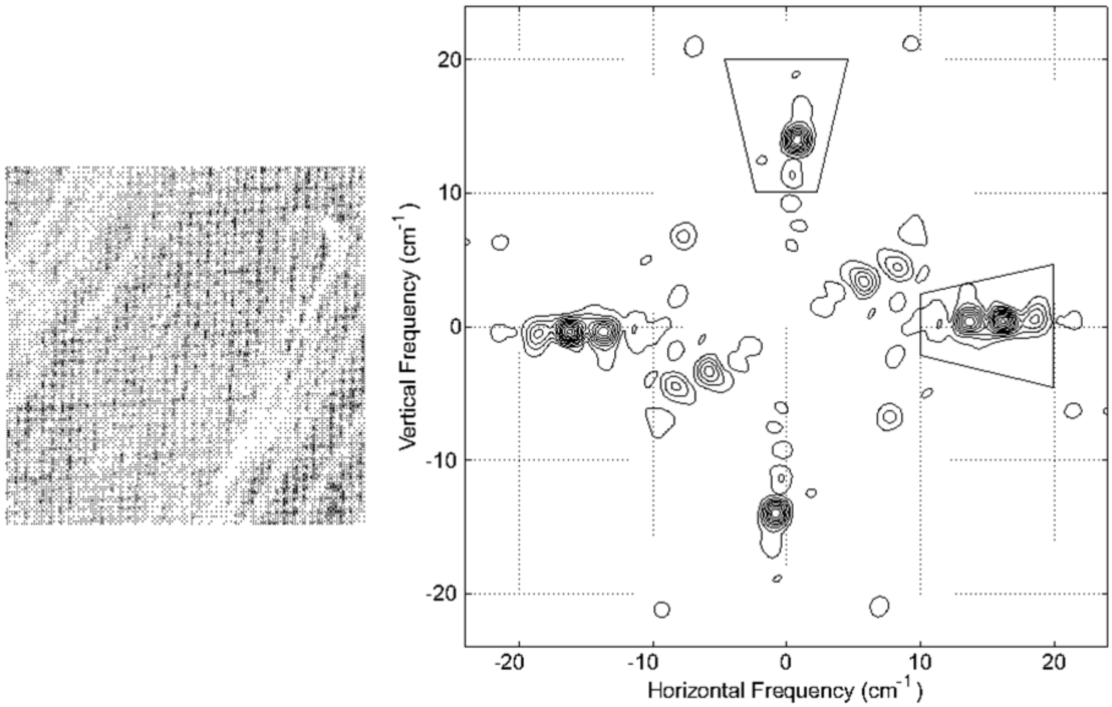
Thread counting algorithms seek the weave density, measured in threads/cm, within a swatch and to study how these counts vary throughout the painting.

3.6 Short-Space Spectrum

2-D Fourier transforms of small areas reveal isolated peaks at the proper vertical and horizontal frequencies.

A square section is extracted from the x-ray, the average subtracted and window applies to obtain spectral detail using the 2D Fourier transform.

Figure 3 represents a simple case: a 1" × 1" swatch from x-ray image and the detailed spectrum computed from a 0.5" × 0.5" square located in the upper left corner of the swatch. The wedges indicate areas where weave-related spectral peaks are found.



Vertical Frequency (cm^{-1})
Horizontal Frequency (cm^{-1})
20
10
0
-10
-20
-20
-10
0
10
20

Figure 3.3

Chapter 4

Methods and Results[1]

4.1 Whole Painting Analysis and Results

4.1.1 Step 1: Obtain the Raw Data

We received x-ray images of paintings from the Van Gogh Museum of Amsterdam. Images usually sampled at 600. Figure 1 shows the x-ray image of Van Gogh's `Backyards of Old Houses in Antwerp in the Snow` (F260) provided by the Van Gogh Museum.

[1] This content is available online at <http://cnx.org/content/m18946/1.1/>.

Figure 4.1

4.1.2 Step 2: Short Time Fourier Analysis

We apply shot time Fourier analysis for each 0.5" × 0.5" swatch. We discarded the outrange frequency peaks and set the value as NaN for the corresponding swatches. For multiple peaks in the frequency region of interest, we accepted the peak that is closest to the median value.

4.1.3 Step 3: Spectra of Whole-Painting

We sampled the short-space spectrum every 1/4" in both directions (horizontal and vertical) for the whole-painting by choosing swatches overlap each other by half in each direction. Thus the spectra of whole-painting were obtained. And we could determine the warp and weft direction of the canvas according to the spread of measurements. Calculations were made in Matlab and took about three hours to analyze F205 on a laptop computer.

Figure 2 shows the resulting spectra of F205.

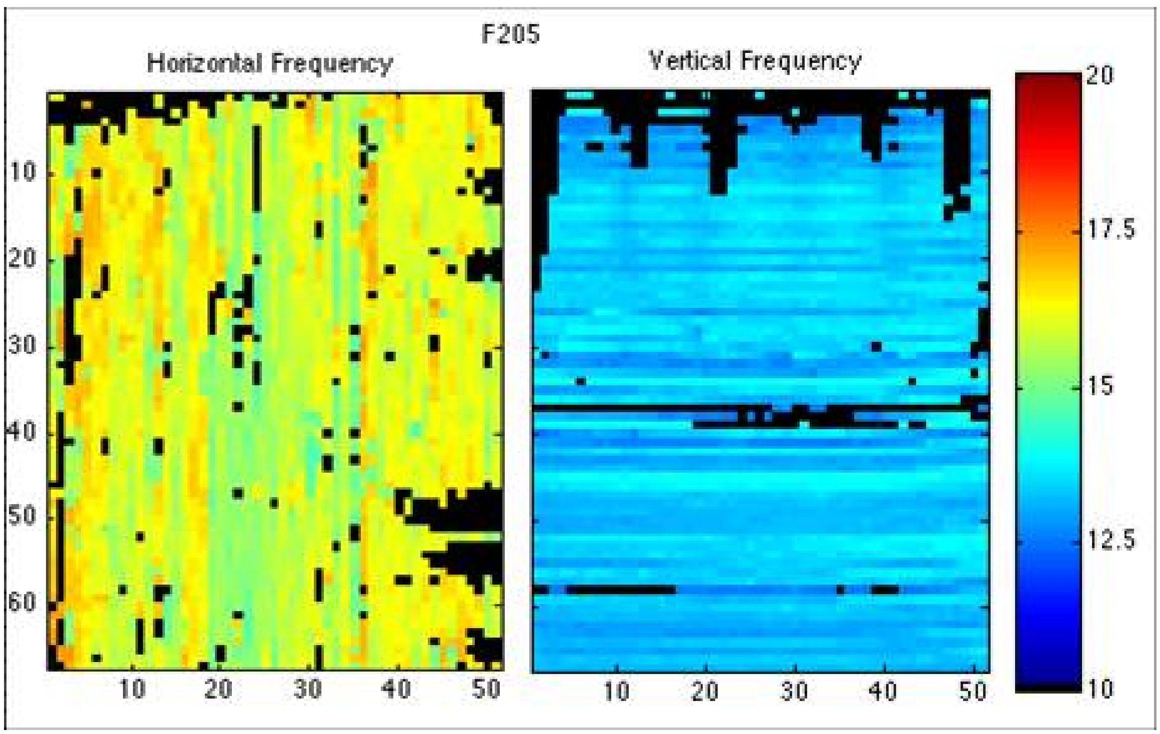


Figure 4.2

4.1.4 Step 4: Deviations Matching Analysis

From the spectra of the whole-painting, we obtained thread count deviations spectra by calculating the distributions of frequencies and subtracting the averages.

Figure 3 and 4 show the vertical thread count deviations of F205 and F260 respectively. Horizontal deviations spectra are not shown here.

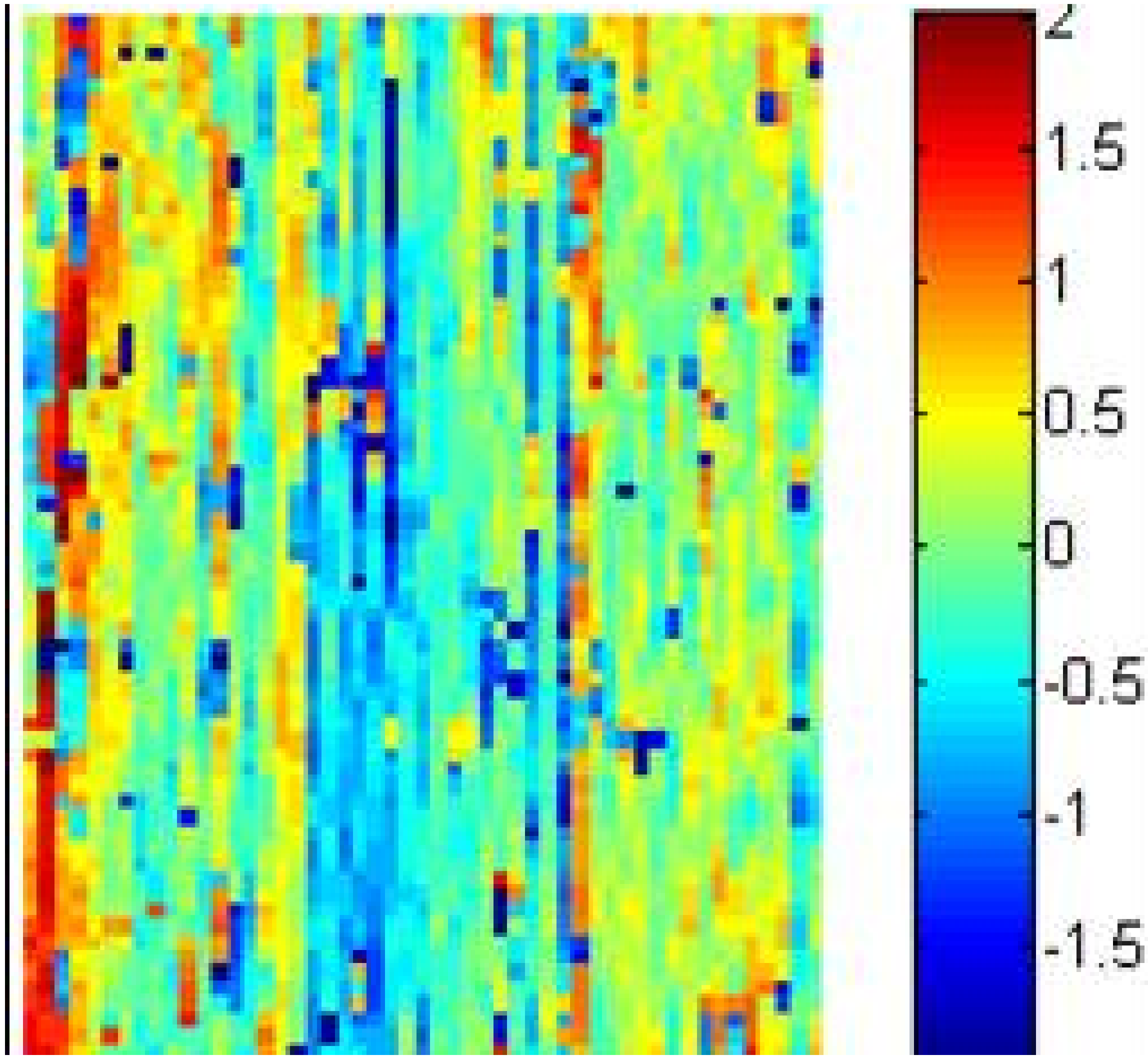


Figure 4.3

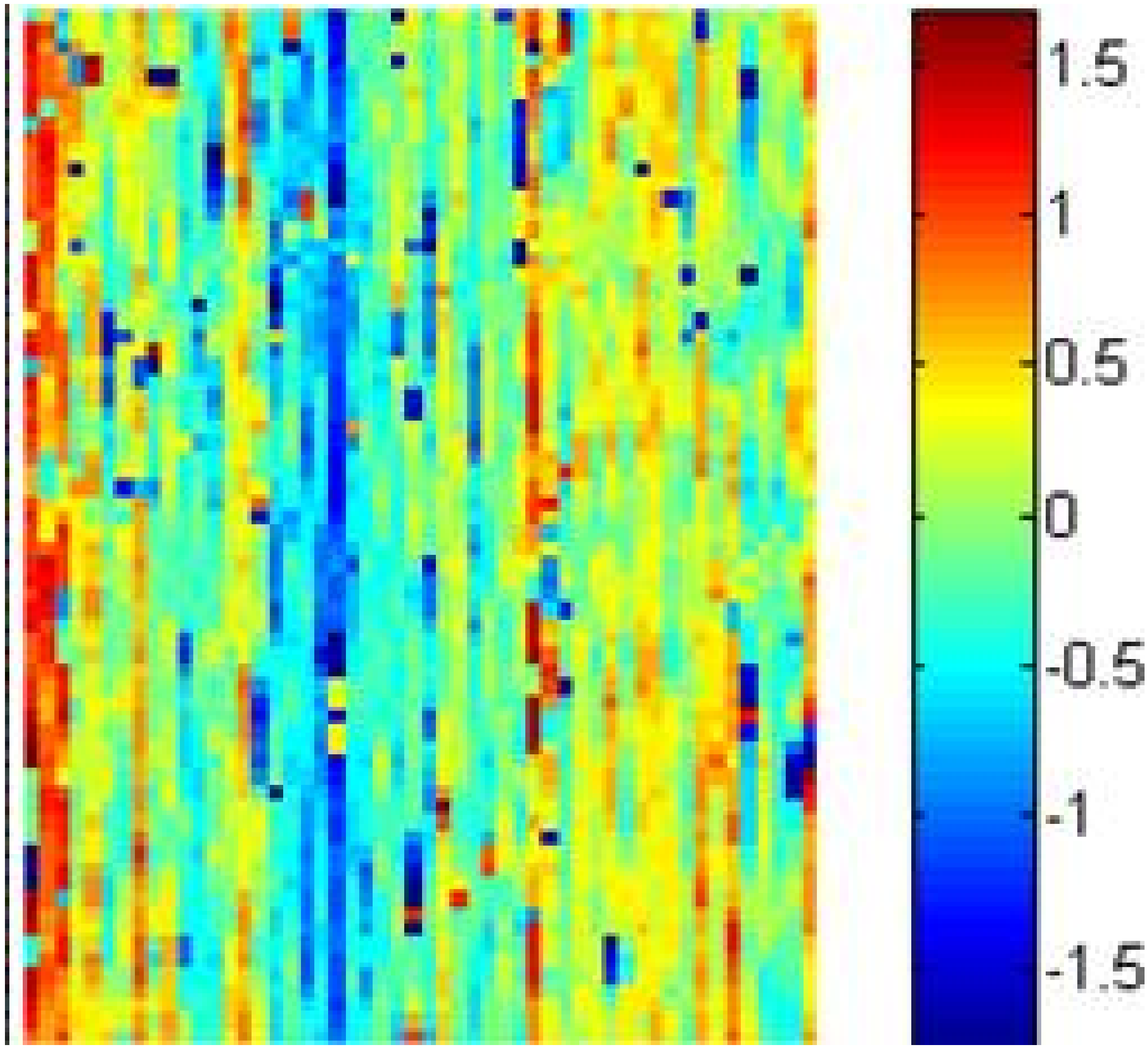


Figure 4.4

Visually, we can see the matching strips between these two painting. But how well do they match?

4.1.5 Step 5: 2D to 1D Conversion

We first computed the 1D thread count deviations from the 2D data. The 1D thread count deviations are obtained by summing the column deviations of 2D data while discarding all the NaNs if any.

Figure 5 and 6 are the corresponding 1D plot of F205 and F260.

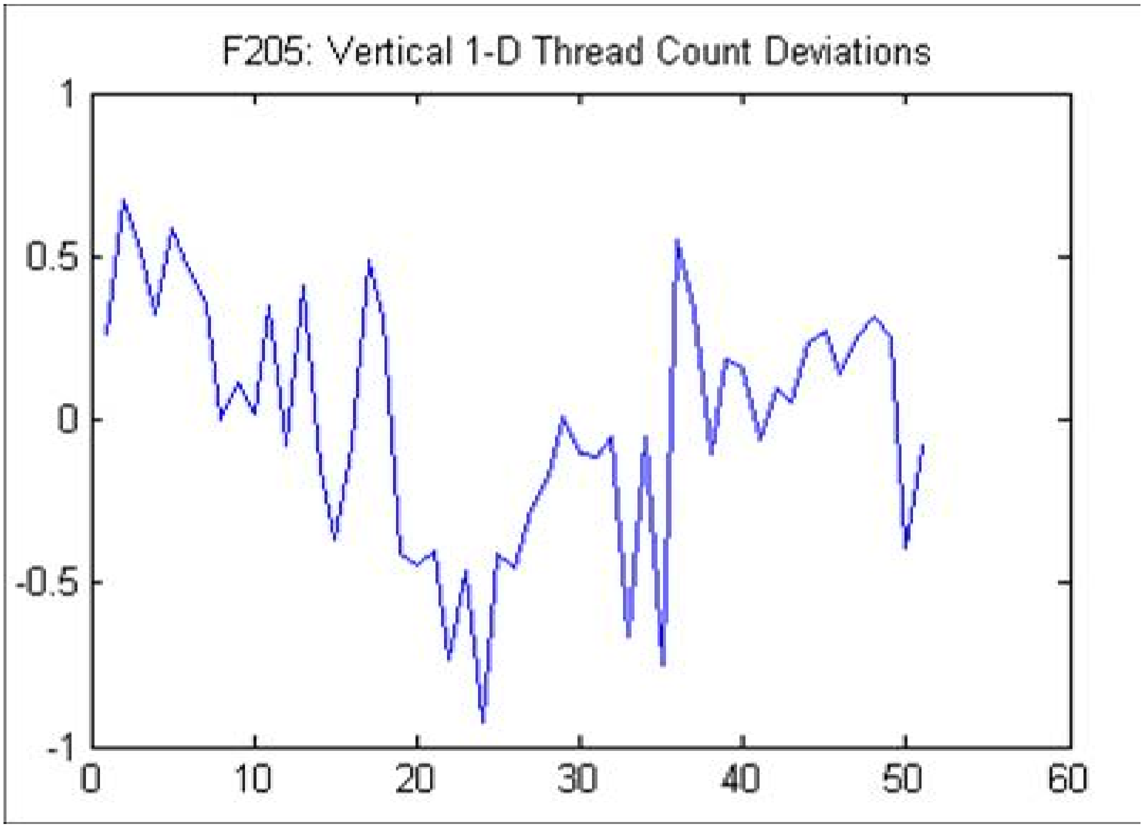

F205: Vertical 1-D Thread Count Deviations
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60

Figure 4.5

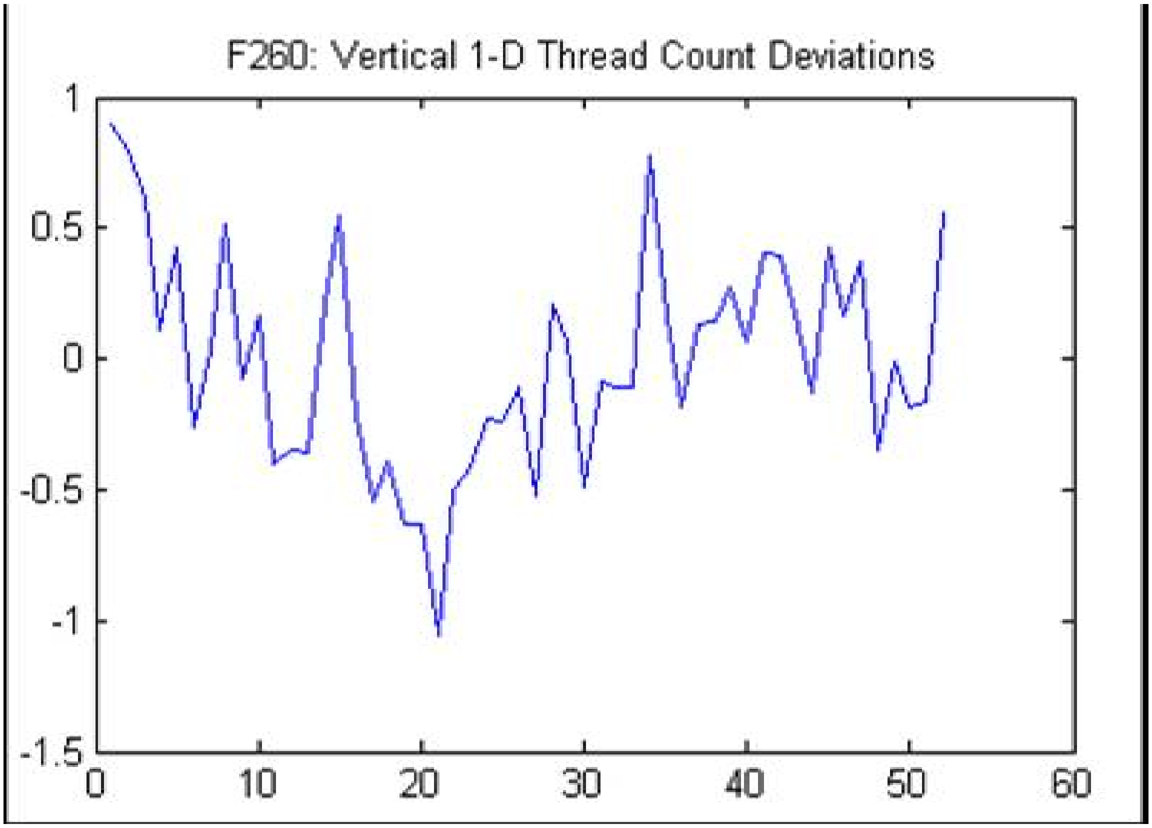


Figure 4.6

We can clearly see the similarities now. But how do they correlate then?

4.1.6 Step 6: Correlation Determination

We then computed unbiased correlation coefficient between 1D vertical thread count deviations of F205 and F260 along the x-axis. You can clearly see a peak (0.7479) appears at the 55th alignment as two paintings are mapped to the matching alignment, or visually "best fit" together. The correlation mapping plot is shown in figure 7.

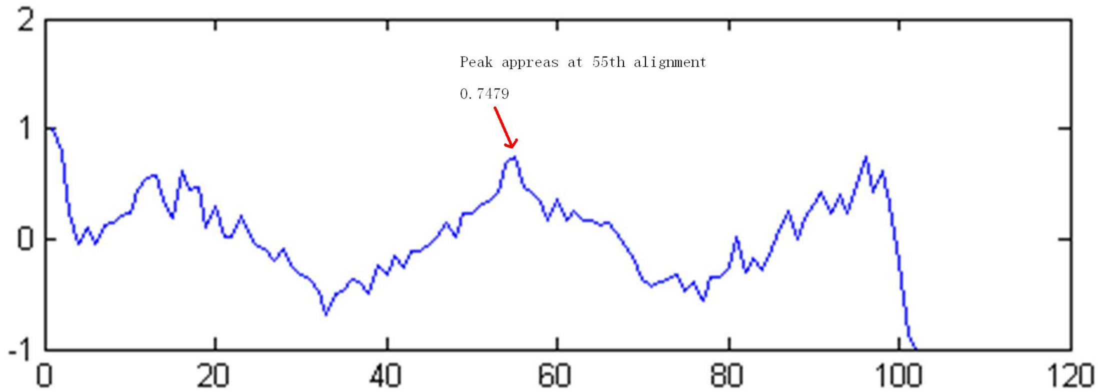


Figure 4.7

The results indicate that these two paintings (F205 and F260) were likely cut from the same canvas roll, sharing the more variable weft direction.

4.2 Orientation Issues in Matching

When we computed the correlation for the paintings, we actually did it four times in our Matlab programs. This is because that any two paintings could possibly match in either direction and each painting could be rotated 0, 90 or 180 degree.

In plotting the correlation mapping, we choose the one that gave the best fit among all possible orientations.

Chapter 5

Conclusions and Future Work[1]

5.1 Conclusions

Clearly, our correlation analysis result is consistent with the matching of F205 and F260 as we can see from the two spectra. **And in fact, F205 and F260 were painted by Van Gogh in the same month in 1885!**

The spectral techniques of our project offer a more efficient and accurate approach to analyzing and sequencing paintings than manual methods. Whole-painting analysis could provide quantitative support for forensic evidence.

The following figure 1 shows the mapping result between all six paintings we worked on. Some paintings have multiple x-ray images due to its big size. Hot spots represent "good matches". Hot spots along the diagonal are expected as weave density deviations should match in the same painting.

[1]This content is available online at <http://cnx.org/content/m18947/1.1/>.

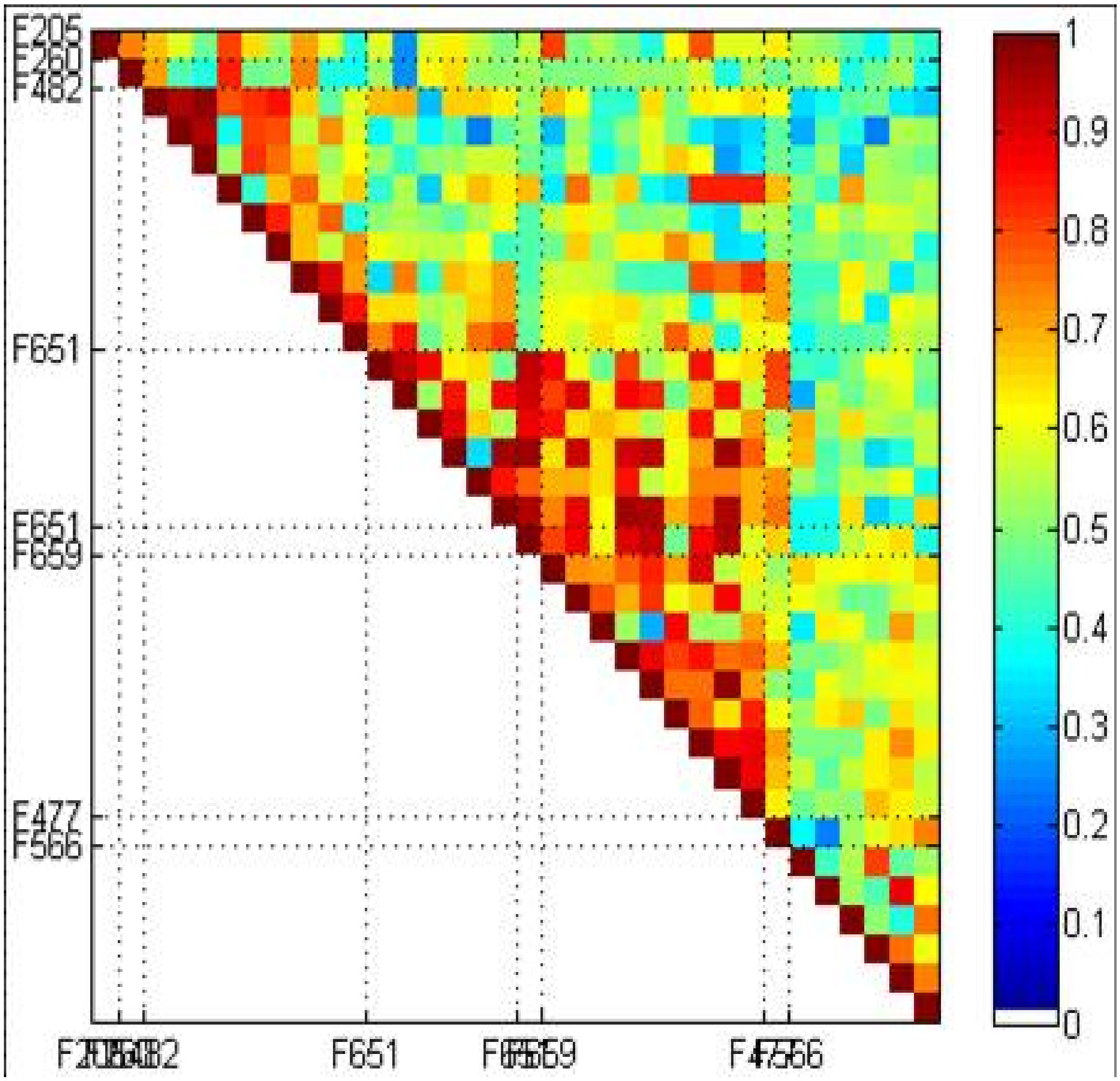


Figure 5.1

Figure 2 shows the same mapping result but with only hot spots left. (With correlation coefficient greater than 0.75)

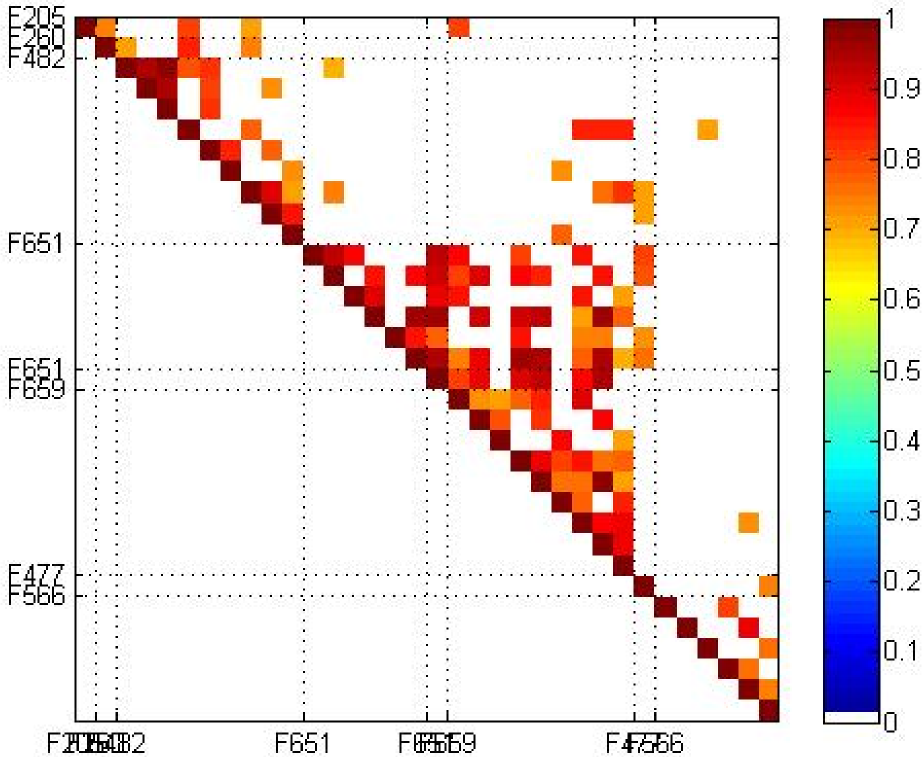


Figure 5.2

5.2 Future Work

5.2.1 Elimination of NaNs in Thread Counting Densities

NaNs are the result of outrange or multiple frequency peaks in the short time Fourier analysis for sample swatches. The reason for these abnormal frequencies are uncertain yet, might due to the x-ray scanning process, imperfect alignment of threads, etc.

5.2.2 Overlap and Critical Values

How big the correlation coefficient should be when we can say that two paintings match? This could vary much according to the size of paintings, alignment directions (warp or weft) and other facts. In addition, we noticed some peaks usually appear at the edge of our correlation plots. This is because small overlap sometimes results in matching accidently. We are working to find a threshold value for overlap and correlation coefficient.

5.2.3 Averages vs. Deviations

Another part of our project involves the Thread Count Average match between paintings which could be used collaborate with the result shown here to reach a more convincing analysis for art forensics.

5.2.4 Applications in Other Fields

Our research philosophy could extend to many related signal processing areas such as speech analysis, image identification and so on. The methods and techniques we developed could be employed not only for canvas paintings but also similar texture materials.

Chapter 6

References and Acknowledgements[1]

6.1 References

D.H. Johnson, C.R. Johnson, Jr., A.G. Klein, W.A. Sethares, H. Lee, E. Hendricks, "A Thread Counting Algorithm for Art Forensics", 2008

6.2 Acknowledgements

We wish to thank Dr. Don Johnson of Rice University's ECE Department.

The thread counting algorithm is collaboration between the Thread Count Automation Project directed by Professor Rick Johnson at Cornell University and Van Gogh Museum, Amsterdam.

Images of this collection are courtesy of Van Gogh Museum, Dr. Don H. Johnson.

[1]This content is available online at <http://cnx.org/content/m18948/1.1/>.

Index of Keywords and Terms

Keywords are listed by the section with that keyword (page numbers are in parentheses). Keywords do not necessarily appear in the text of the page. They are merely associated with that section. *Ex.* apples, § 1.1 (1) **Terms** are referenced by the page they appear on. *Ex.* apples, 1

Attributions

Frequency Analysis for Art Forensics
Frequency distributions of weave density should match if two paintings are from the same canvas roll according to the thread counting algorithm we employ.

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