



# Geometric tight frame based stylometry for art authentication of van Gogh paintings



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## ARTICLE INFO

### Article history:

Received 17 February 2015

Received in revised form 14

November 2015

Accepted 24 November 2015

Available online 2 December 2015

Communicated by Spec. Issue Guest Editor

### Keywords:

Art authentication

Stylometry

Tight frame

Feature selection

Outlier detection

## ABSTRACT

This paper is about authenticating genuine van Gogh paintings from forgeries. The paintings used in the test in this paper are provided by van Gogh Museum and Kröller-Müller Museum. The authentication process depends on two key steps: feature extraction and outlier detection. In this paper, a geometric tight frame and some simple statistics of the tight frame coefficients are used to extract features from the paintings. Then a forward stage-wise rank boosting is used to select a small set of features for more accurate classification so that van Gogh paintings are highly concentrated towards some center point while forgeries are spread out as outliers. Numerical results show that our method can achieve 86.08% classification accuracy under the leave-one-out cross-validation procedure. Our method also identifies five features that are much more predominant than other features. Using just these five features for classification, our method can give 88.61% classification accuracy which is the highest so far reported in literature. Evaluation of the five features is also performed on two hundred datasets generated by bootstrap sampling with replacement. The median and the mean are 88.61% and 87.77% respectively. Our results show that a small set of statistics of the tight frame coefficients along certain orientations can serve as discriminative features for van Gogh paintings. It is more important to look at the tail distributions of such directional coefficients than mean values and standard deviations. It reflects a highly consistent style in van Gogh's brushstroke movements, where many forgeries demonstrate a more diverse spread in these features.

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## 1. Introduction

Art authentication is the identification of genuine paintings by famous artists and detection of forgery paintings by imitators. The traditional way in art authentication is to rely on the discerning eyes and experience of experts who are dedicated in the work and life of the artist(s). Physical means such as ultraviolet fluorescence [23], infrared reflectography [10], x-ray radiography [27], painting sampling [6], and canvas

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weave count [3] have also been used for art authentication. The term *stylometry* refers to the application of statistical or quantitative techniques for authorship and style evolution in literary arts [28]. In the past decade, research in stylometry for paintings has benefited from the rapid progress in image data acquisition technology. By using high-resolution digital images of artists' collections, image analysis researchers and art historians have engaged in cross-disciplinary stylometric analysis of art paintings via computational techniques [1,2,17–20,24,29,30].

Although many art authentication methods were proposed and used, the authorship of many paintings is still questioned by experts, with different art scholars having different opinions. Stylometry for paintings, in particular, is still a long way from being a mature field, even for paintings from well-known artists. Here, we propose a new stylometric technique for art authentication of Vincent van Gogh paintings. Our results on 79 paintings provided by van Gogh Museum and Kröller-Müller Museum show that our method is better than existing van Gogh paintings authentication methods [18,24,29].

Stylometry is based on the assumption that there are some distinctions in styles among different artists. Each artist exhibited particular traces of natural style and habitual physical movements when painting. Therefore, characteristics reflecting these habits can be considered as features to identify the authorship of paintings. In the past two decades, various specialized features have been used in stylometric analysis, and many paintings are authenticated. An early study was given by Taylor et al. in 1999 on fractal analysis of Pollock's drip paintings [30]. They showed that the fractal dimensions increased steadily through Pollock's career and fractal analysis could be used as a quantitative and objective technique for analyzing his paintings. In a 2004 paper by Lyu et al. [24], the moment statistics of wavelet coefficients and the log error in a linear predictor are used as features to authenticate the drawings by Pieter Bruegel the Elder. In the same year, Li and Wang [19] put 2D multi-resolution Hidden Markov Model (HMM) in use to classify paintings from some China's famous artists in different dynasty periods. Later, Berezhnoy et al. [2] gave an orientation extraction technique based on circular filters for brushstroke extraction. Recently, the moment statistics of 2-D Empirical Mode Decomposition (EMD) coefficients were used by Hughes et al. [17] for stylometric analysis of drawings by Pieter Bruegel the Elder and Rembrandt van Rijn. For each forgery in their dataset, a binary classifier was trained based on this forgery together with all but one genuine drawings. Then the left-out genuine drawing was classified according to the trained classifier. However, in the paper, there is no authentication done on the forgery drawings.

In 2008, three research groups from Penn State, Princeton, and Tilburg focusing on authenticating van Gogh paintings reported their analysis of van Gogh's brushstrokes in [18]. In the work of the Penn state group, the similarity among paintings were assessed via texture and brushstroke geometry modeling. The Princeton group applied the complex wavelet and Hidden Markov Tree (HMT) for feature extraction, and then similarity distances between paintings were calculated using the first few features ranked according to their effectiveness in distinguishing van Gogh's and non-van Gogh's patches. Finally a multidimensional scaling embeds the paintings into a 3D space where the separation of genuine paintings from forgery ones was done. Binary support vector machine was used to determine the authorship by the Tilburg University group. It is based on the fact that the total energy, as calculated using the Gabor wavelet coefficients from the patches, was larger in the non-van Gogh's paintings. These studies are quite encouraging as initial works for identifying the authorship of van Gogh paintings.

In 2012, Li et al. [20] made an effort to extract those visually salient brushstrokes of van Gogh based on an integrative technique of both edge detection and clustering-based segmentation. With the extracted brushstrokes, some definitions of brushstroke features for art authentication were given in distinguishing van Gogh paintings from forgeries. In their numerical test, they compared the brushstrokes obtained manually with those extracted using their algorithm and showed that the combined brushstroke features were consistent throughout van Gogh's works during his French periods (1886–1890).

More recently in 2013, Qi et al. [29] use background selection and wavelet-HMT-based Fisher information distance for authorship and dating of impressionist and post-impressionist paintings. Two novel points were

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