Computerized visual analysis of paintings

*Igor E. Berezhnoy, Eric O. Postma & Jaap van den Herik**

The paper provides insights into our efforts to develop techniques for the analysis of visual art. The AUTHENTIC project aims at creating a collection of software tools to support art experts in their assessments of the authenticity of paintings. We describe our progress on the automatic analysis of two visual features of the paintings of Vincent van Gogh: colour and texture. The colour-analysis technique is shown to confirm the generally known increase in the use of complementary colours accompanying Van Gogh's move to France. The texture-analysis technique reveals two main clusters of brushstroke shapes in a single painting. These qualifying results lead us to conclude that the use of advanced digital analysis techniques will change the way in which the authentication of visual art is performed.

1 Introduction

The assessment of paintings is largely performed by human art experts. Connoisseurship has played an important role throughout the history of art. Undoubtedly, the assessments of skilled experts are of great value to the visual arts. However, inevitably human judgements are highly subjective and prone to error. Occasionally, experts judging the authenticity of paintings made mistakes and were more then once forced to revise their opinions in the light of objective evidence. So far, objective evidence bearing on the issue of authenticity came from chemical analysis, infrared reflectography, and other examinations of the physical properties of the painting such as dendrology. In the context of the AUTHENTIC project, we attempt to develop digital techniques for an objective examination of the visual properties of paintings. The aim of the AUTHENTIC project is to develop a set of digital tools for the art expert. Using modern image-analysis and machine-learning techniques, the visual structure of (digital reproductions of) paintings can be quantified and incorporated into the overall judgement of the expert [5].

In this paper we focus on the analysis of two visual features of paintings: colour and texture. The analysis of colour is performed using a special technique that detects transitions of the two main complementary-colour pairs: red-green and yellow-blue. The analysis of texture proceeds using a tailor-made brushstroke-extraction technique to quantify the shape of brushstrokes. Both techniques are applied to digitized and colour-calibrated paintings of Vincent van Gogh. The outline of the paper is as follows. Section 2 describes the colour-analysis technique and presents the results obtained by applying the technique on 169 paintings by Van Gogh. Section 3 presents our qualifying results on the brushstroke analysis applied to the same collection of paintings. Then, in section 4 we discuss how our analysis techniques will change the way authentication and art analysis will be performed in the near future. Finally, in section 5 we draw conclusions.

* Institute for Knowledge and Agent Technology (IKAT) Maastricht University, Maastricht, The Netherlands

2 The automatic analysis of complementary colours

During his French period, Vincent van Gogh became aware of the perceptual impact of colours in paintings. He knew the effects of complementary colour pairs (*e.g.*, red-green and yellow-blue) and started to make abundant use of these colours in his paintings [1,4]. For an adequate analysis, we developed a technique that detects complementary-colour transitions in Van Gogh's paintings. In this section we describe the perceptual mechanisms underlying colour perception by focusing on opponent colours (2.1), explain the spatial filters employed to mimic these mechanisms (2.2), and present our qualifying results on the analysis of the complementary colours in Van Gogh's paintings (2.3).

2.1 Opponent colours

Colour is a mental construct (see, *e.g.*, [8,11]). Therefore, when digitally analysing colour, the brain mechanisms responsible for generating a colour experience have to be taken into account (insofar as possible). The human visual system processes chromatic signals using three types of retinal cone photoreceptors. Subsequently, the neural transformation of the signals yields an opponent-colour representation in which chromatic information is expressed in three channels: a red-green channel, a yellow-blue channel, and a black-white (luminance) channel [9,10,12,13]. The red-green and yellow-blue channels are very sensitive to complementary colour pairs. For instance, the red-green channel is sensitive to complementary colour pairs that include either red or green. Recent evidence suggests that the opponent channels arise naturally as the independent components of natural images [7]. Biological studies have revealed that individual neurons in the visual system respond to opponent colours [3].

2.2 Spatial filters

Our colour-analysis technique mimics the opponent-colour mechanism of the human visual system [13]. The technique relies on spatial filters that respond to red-green and yellow-blue transitions in the image. An example of such a filter is shown in figure 1. The figure shows a red-green filter response ('red-green value') as a function of the relative horizontal (x) and vertical (y) location of the image. The response of the filter is maximal for red-green colour transitions in the painting that match the filter location, scale, and orientation. In order to capture red-green and yellow-blue transitions

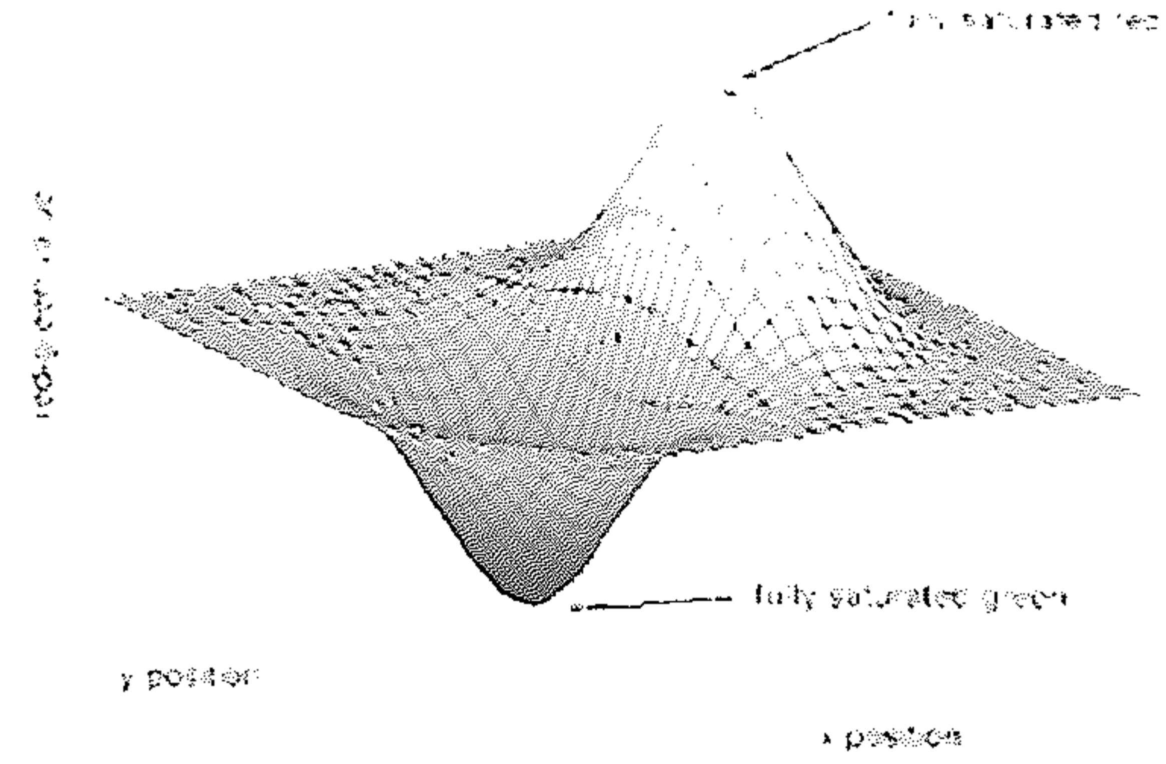

Figure 1. Example of a red-green spatial filter

at all relevant locations, scales, and orientations, a digital image of a painting is filtered by red-green and yellow-blue filters. They are centred at all image locations, and have several scales, i.e., image areas ranging in size from small (20 × 20 pixels) to large (200 × 200 pixels), and a number of orientations evenly distributed on the interval from 0 to 360 degrees. The average response of all these filters yields an (average) opponency value that indicates the amount of complementary-colour transitions in a painting.

2.3 Colour-analysis results

To quantify the usage of complementary colours in Van Gogh's paintings during his lifetime, we determined the average opponency values for 169 paintings created throughout his life. Van Gogh's paintings have been catalogued using the so-called Jan Hulsker or JH numbers [6]. These numbers correspond fairly accurately with the chronological order in which the paintings were created. In figure 2, we present the (average) opponency value as a function of the JH number for the range of about 100 (Dutch period) to about 2000 (French period). A clear transition is observed from JH1000 towards JH1400 which corresponds roughly with Van Gogh's move towards France.

Our result is consistent with the prevailing opinion of art experts and provides an objective measure of the usage of colour in individual paintings. As an example, figure 3 shows Van Gogh's painting *Landschap met bomen en vrouwelijke figuur* (JH 1848). The inset displays the image obtained by selecting high opponency values, only. The contours of the female figure are clearly visible indicating that Van Gogh employed complementary-colour transitions to emphasise contours.

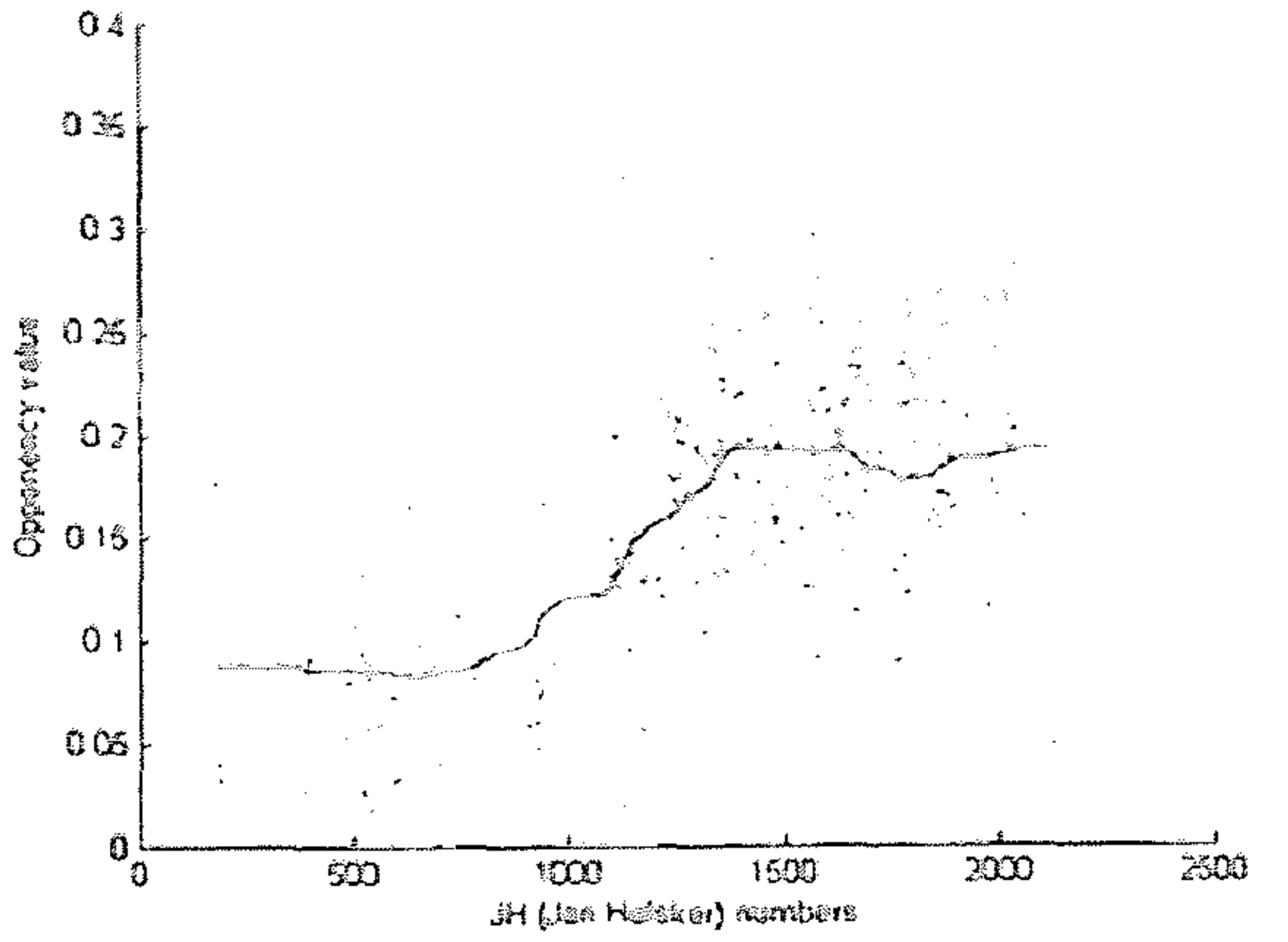

Figure 2. Average opponency value as a function of Jan Hulsker number. The dots represent the opponency values for individual paintings, the curve approximates the running average

Figure 3. The painting 'Landschap met bomen en vrouwelijke figuur' Saint-Rémy, 1889, (JH 1848). The inset displays the image obtained by selecting high opponency values only. The contours of the female figure are clearly visible

3 The automatic analysis of brushstroke texture

Texture is the second visual feature for which we developed an analysis technique. This feature reflects the statistical properties of small image regions. The statistical properties are dominated by visual contours, i.e., transitions in intensity along a contour. In Van Gogh's paintings the local texture is determined by the way he applied brushstrokes on the canvas.

3.1 Van Gogh's brushstroke alphabet

Art experts agree on the observation that the nature and distribution of brushstrokes is highly characteristic for a painter. This applies especially to Van Gogh whose brushstrokes are clearly visible due to his painting style. The brushstrokes of Van Gogh constitute a kind of alphabet, the elements of which are repeatedly used in his paintings. Examples of elements of Van Gogh's brushstroke alphabet are curved strokes, repetitive parallel strokes, and circular strokes. In an attempt to detect and quantify the occurrence of the elements of the alphabet, we started with the extraction of the shape of brushstrokes in a single painting.

3.2 Brushstroke extraction

The digital extraction of brushstrokes proceeds in two steps: (I) contour enhancement, and (II) quantification of brushstroke shape. Below, we provide a brief outline of both steps.

I. Contour enhancement. Although the brushstrokes are visually obvious for human observers, their automatic extraction is far from trivial. In order to enhance the brushstroke contours and suppress any other visual structure, we apply a circular filter to the painting. This filter enhances the parallel contours, characteristic of brushstrokes, irrespective of their orientation. Figure 4 illustrates the circular filter. The vertical axis represents the filter response; the two planar axes represent the image plane. The main parameter of the filter is the diameter of the circle which is optimised to match the average separation of the parallel contours of the brushstroke. Figure 5 shows the result of applying the (optimised) circular filter to Van Gogh's Korenveld met kraaien (JH 2117). The brushstroke contours are clearly visible.

II. Quantification of a brushstroke shape. The quantification of a brushstroke shape proceeds in three steps. Firstly, the closed contours are filled. Figure 6A illustrates a filled closed contour corresponding to a single brushstroke (or brushstroke fragment). Secondly, the closed contour is skeletonized yielding a thinned line-like representation of the brushstroke (figure 6B). Thirdly, the thinned brushstroke is fitted to an Nth order polynomial. The value of N is proportional to the complexity of the fitted curve. Figure 6C shows the result for N=3. Small irregularities are removed in this step. With these three steps, the brushstroke contours

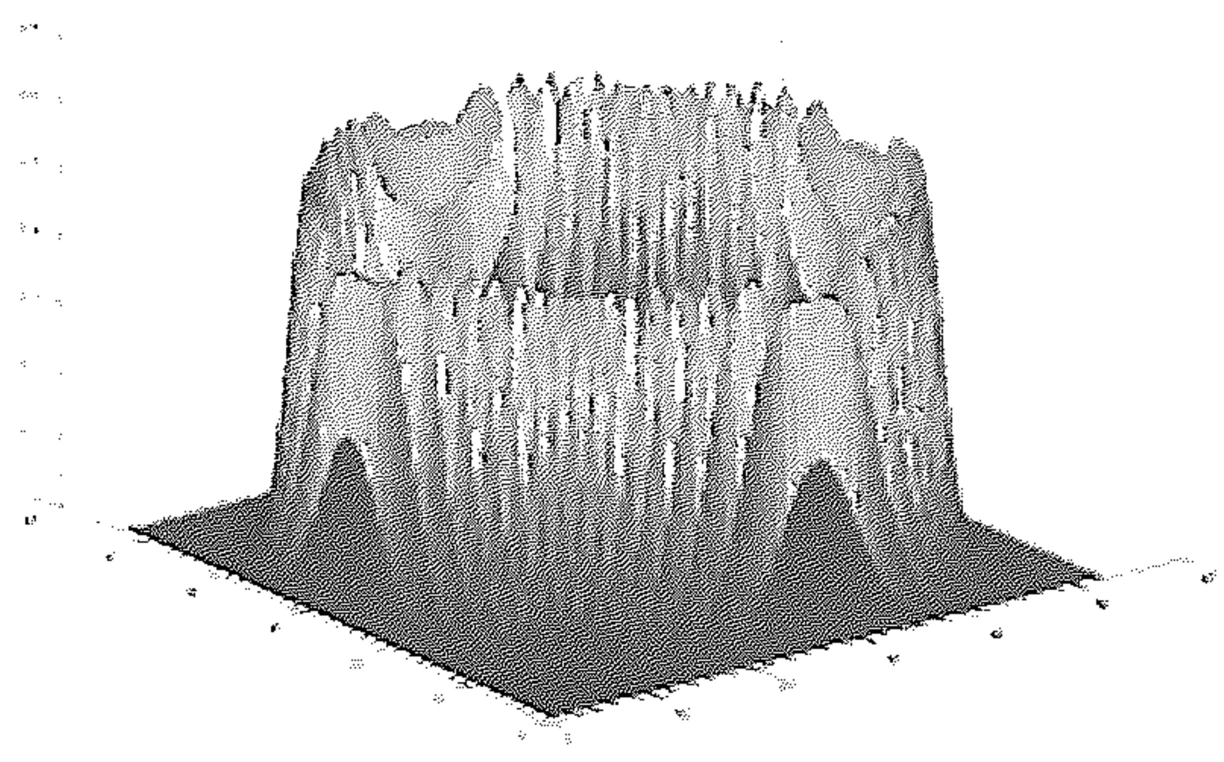

Figure 4. Illustration of the circular filter

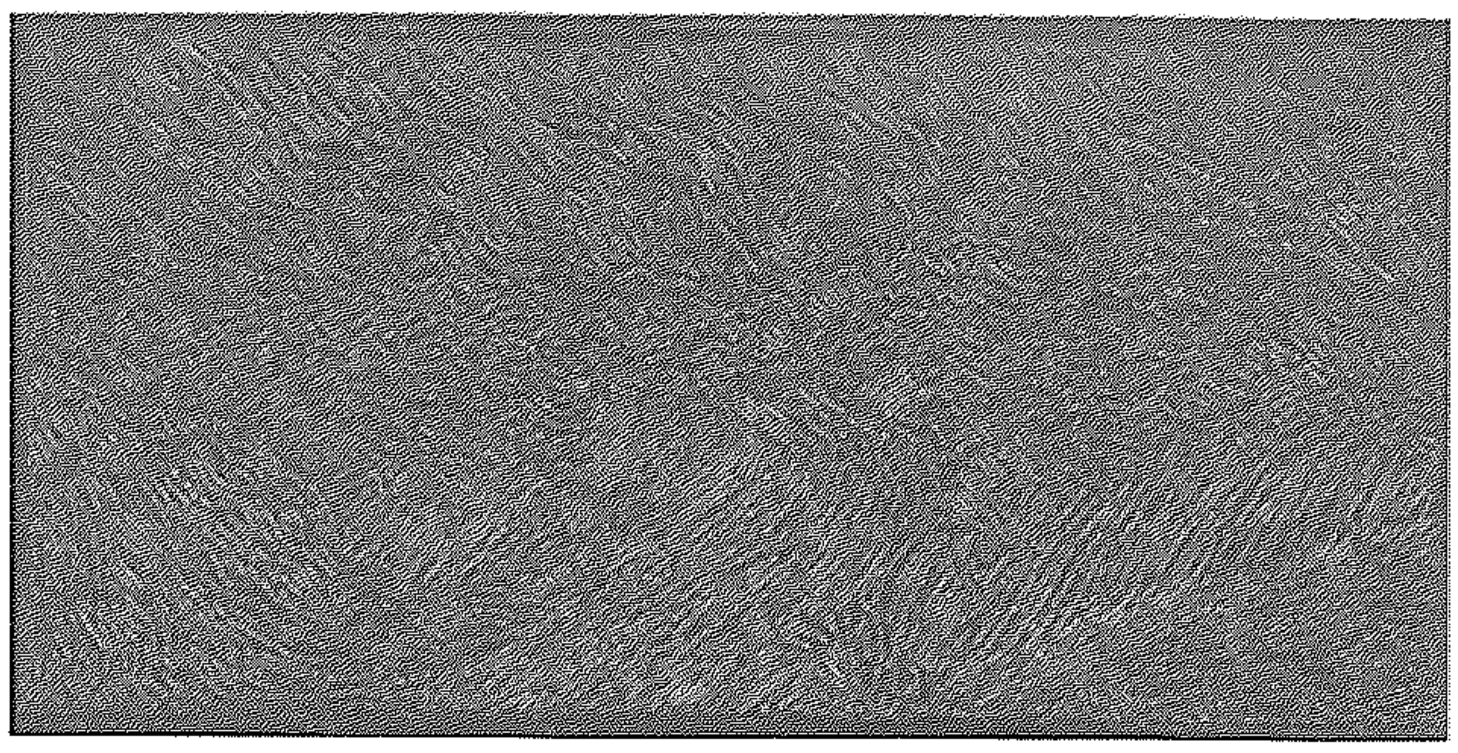

Figure 5. The result obtained after applying the circular filter to Van Gogh's 'Korenveld met kraaien', Auvers-sur-Oise, 1890 (JH 2117).

are transformed into a compact quantitative representation, i.e., into N polynomial coefficients.

3.3 Texture-analysis results

The quantitative representation of brushstrokes enables the application of statistical analysis and learning techniques to discover painter-specific regularities. We have applied our brushstroke-extraction technique to 169 paintings of Van Gogh which resulted in over 60 thousand separable brushstrokes (and brushstroke fragments). Each of these brushstrokes is transformed into three coefficients. Figure 7 shows a plot of the distribution of the two relevant coefficients (i.e., the polynomial equals: $coef1\, x + coef2\, x^2$). The figure reveals a clear structure; the coefficients are grouped into two largely overlapping clusters. In terms of brushstroke shapes, the distribution of points represent brushstrokes ranging from slightly curved leftwards to slightly curved rightwards. Such brushstrokes correspond to letters of Van Gogh's alphabet. Currently, we are undertaking a detailed analysis of sub-clusters within the displayed distribution and within other distributions to find additional letters of the brushstroke alphabet.

Discussion

Our analysis techniques are only the start of a promising development to explore the possibilities of automatic visual examination of Van Gogh's paintings. The qualifying results on the analysis of colour and texture reveal a glimpse of the potential of digital image-analysis and machine-learning techniques. In the coming years, we will extend our techniques and results in order to obtain a full-fledged toolbox to support the art expert in his judgement.

Our techniques *support* rather than replace the expert for two main reasons. The first reason is that our techniques may reveal statistical regularities that are caused by factors other than the painting style. For instance, the distribution of brushstroke shapes may be biased by the storage or restoration of a painting. The identification of such a bias requires domain knowledge. The second reason is that our techniques are necessarily limited to low-level features such as colour, texture, and shape. High-level features such as the 'theme' of a painting are beyond the scope of present-day techniques. Their appreciation requires cultural and art-historical knowledge.

Conclusions

At present, the cultural heritage benefits insufficiently from innovations in computer science. In this contribution we provided some insights into our progress in the AUTHENTIC project. For the first time, objective visual analysis techniques are applied to the paintings of Vincent van Gogh. From the results given above and published elsewhere [2] we may conclude that the use of advanced digital analysis techniques will change the way in which the authentication of visual art is currently performed.

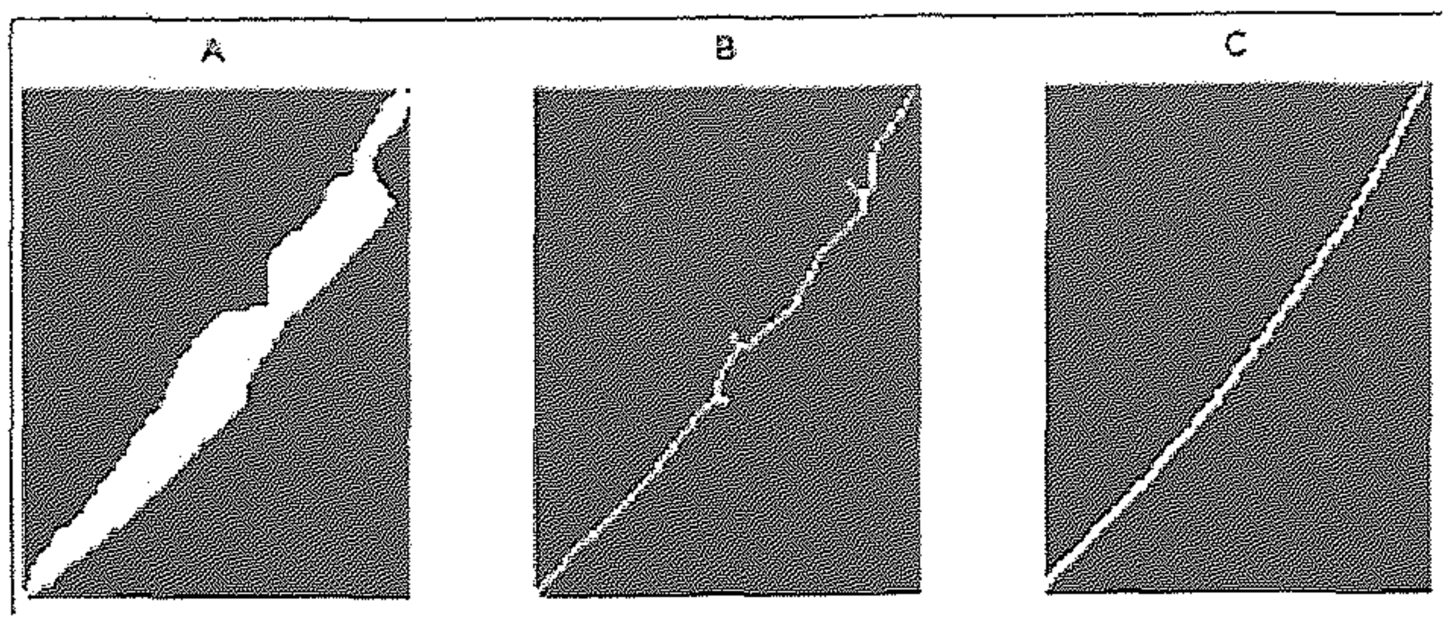

Figure 6. Brushstroke quantification in three steps: (A) filling closed curves, (B) skeletonizing the filled curve, and (C) fitting an Nth order polynomial.

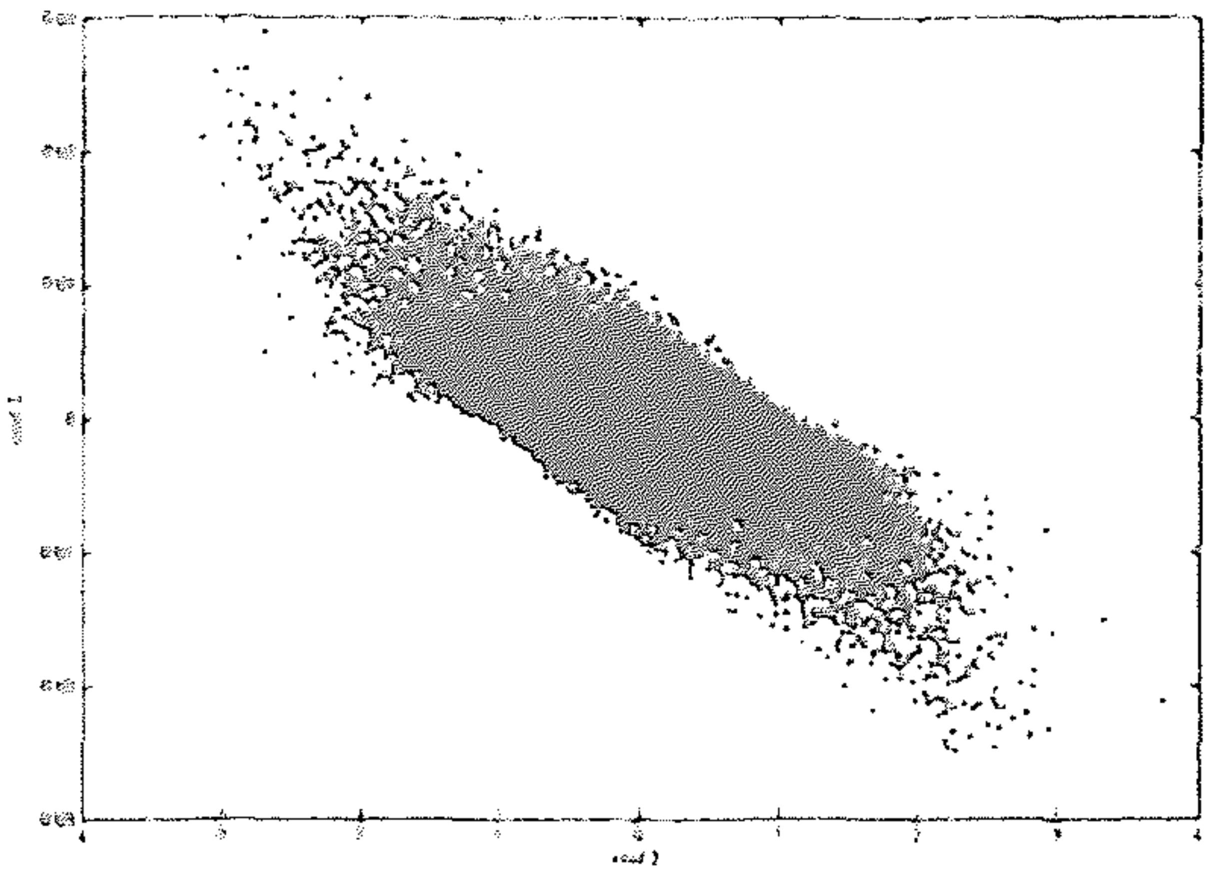

Figure 7. Illustrative results of the brushstroke-analysis technique. The plot shows the distribution of the second and third coefficient of a third-order polynomial fit to the brushstrokes in 169 paintings of Van Gogh.

Acknowledgement

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