Stroke Boundary Analysis for Identification of Drawing Tools

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Abstract. An algorithm for the automatic identification of drawing tools based on the appearance of the stroke boundary is presented. The purpose of this stroke analysis is the determination of drawing tools in underdrawings - the basic concept of an artist - in ancient panel paintings. This information allows significant support for a systematic stylistic approach in the analysis of paintings. Up to now the identification of drawing tools is performed by an expert visually. Our tool will support the expert to investigate larger numbers of underdrawings, provides objective and reproducible information and simplifies comparison of different underdrawings. Stroke analysis in paintings is related to the extraction and recognition of handwritings, therefore similar techniques to stroke analysis are used. Following the segmentation, the approximation of the stroke boundary is done by active contours with different parameters. Deviations between a rigid and elastic "snake" are used as descriptive features for differentiation between drawing tools. Results of the algorithm are presented for sets of three different types of strokes.

1 Introduction

Computer aided analysis is an important tool for the examination of works of art [1]. Within an interdisciplinary project between the fields art history and image analysis we are developing a system to investigate infrared images (infrared reflectograms [2]) of medieval and Renaissance panel paintings with methods of digital image processing and analysis. In conservation and art history three prominent questions are of particular interest. The first question deals with the development of underdrawings and their relations to other drawings and between underdrawing and the covering painting. Secondly, art historians and restorers are interested in the style of the underdrawing, and questions whether the underdrawing is sketchy, freehand or a copy from a template. Finally an important question is, what kind of materials and drawing tools are used in an underdrawing [3].

This paper will contribute to answering the third question and addresses the automatic identification of drawing tools used in the underdrawing of medieval paintings. This is a first step towards a subsequent stylistic analysis of underdrawings and a classification of painters. We present a method that analyzes the

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visual appearance of the stroke boundary. Up to now appearance based analysis of drawing tools is made only visually by experts. A problem of visual analysis is, that it is often not possible to inspect a large amount of drawings as a whole and in detail and therefore the analysis usually is reduced to selected objects and to certain regions of a painting. The restricted human optical retentiveness further complicates the comparison of different underdrawings concerning drawing tools, drawing materials, and stroke characteristics. Automatic analysis tools will objectify the analysis. They will speed up the recognition process, will provide objective and reproducible data and support the experts in studying underdrawings.

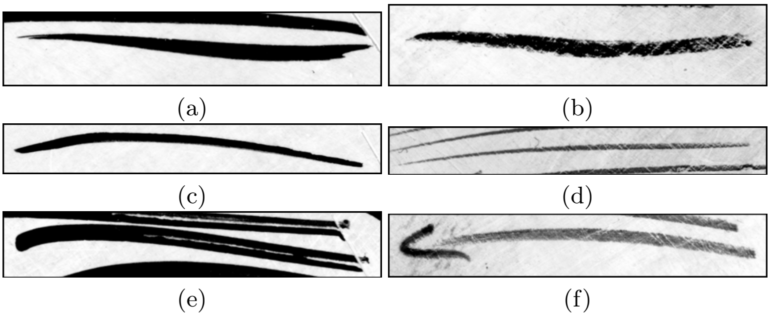


Fig. 1. Stroke details showing tools using fluid materials on the left, brush (a), quill (c), reed pen (e) and dry material tools on the right, black chalk (b), silver point (d) and graphite (f).

The paper is organized as follows. In Section 2 an overview about the characteristics of drawing tools and materials used in medieval underdrawings is given. The analysis process, like the standard approach, is split into a segmentation step, a refinement step and a feature extraction step which are described in Section 3. Section 4 will present and discuss the results obtained with our method. Whereas Section 5 will give an brief overview about work in progress and on future work.

2 Characterizing Drawing Tools / Materials

Drawing tools, used in medieval panel paintings can be categorized into two different types, into those that are fluid and into a group consisting of dry drawing material [3]. In Figure 1 six examples of a stroke for both of the groups are depicted. Three strokes represent the class of drawing tools using fluid materials (a,c,e) and three strokes represent dry materials (b,d,f). These examples have been taken from a panel prepared for our experiments by a restorer.

Our analysis approach is based on the observation that prominent characteristics of drawn strokes are variations of shape and variations of the intensity in the drawing direction. Table 1 gives an overview about the characteristics of the

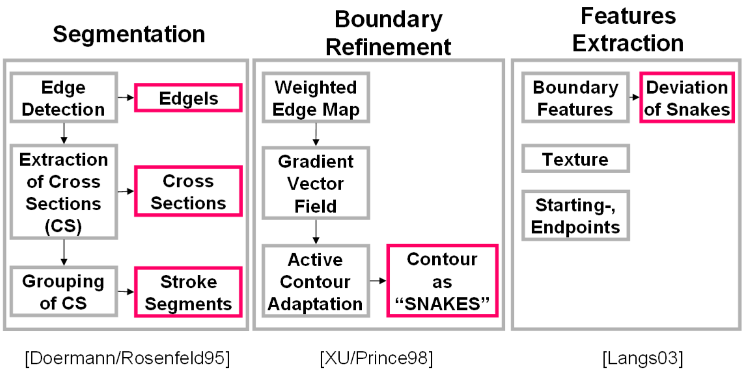


Fig. 2. Schematic diagram of our approach

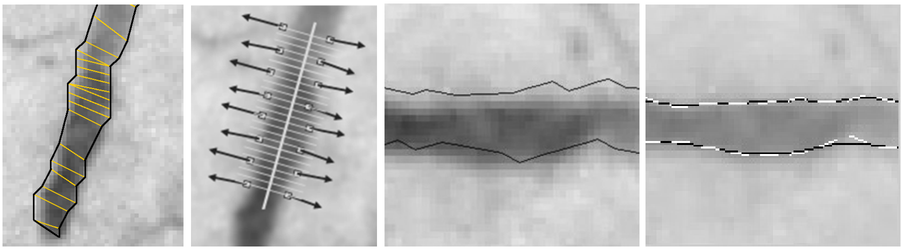
two groups of drawing tools. The first characteristic we analyzed is the boundary of a stroke. It can be observed, that there are variations in smoothness depending on the drawing tool used. While strokes applied with a pen or brush using a fluid medium show a smoother boundary, the boundary of strokes applied with a dry material, e.g. black chalk or graphite is less smooth. This observation is used in the method presented in the next section.

Table 1. Characteristics of different drawing tools and materials

Tools/Materials	**Characteristics**
fluid materials	**fluid lines**
- paint or ink applied by pen or brush	- **continuous and smooth**
	- vary in width and density
	- pooling of paint at the edges
	- droplet at the end
	- different endings (brush/pen)
dry materials	**dry lines**
- charcoal	- **less continuous and smooth**
- chalks	- less variation in width
- metal points	- more granular
- graphite	

3 Stroke Segmentation and Feature Extraction

Stroke segmentation in paintings is related to the extraction and recognition of handwritings [4]. Letters and words in Western languages and symbols or signs in Chinese or Japanese languages are built of manually drawn strokes or lines. Many approaches start with thresholding and thinning methods. While these methods are fast and save resources, valuable information for a more detailed analysis



(a) (b) (c) (d)

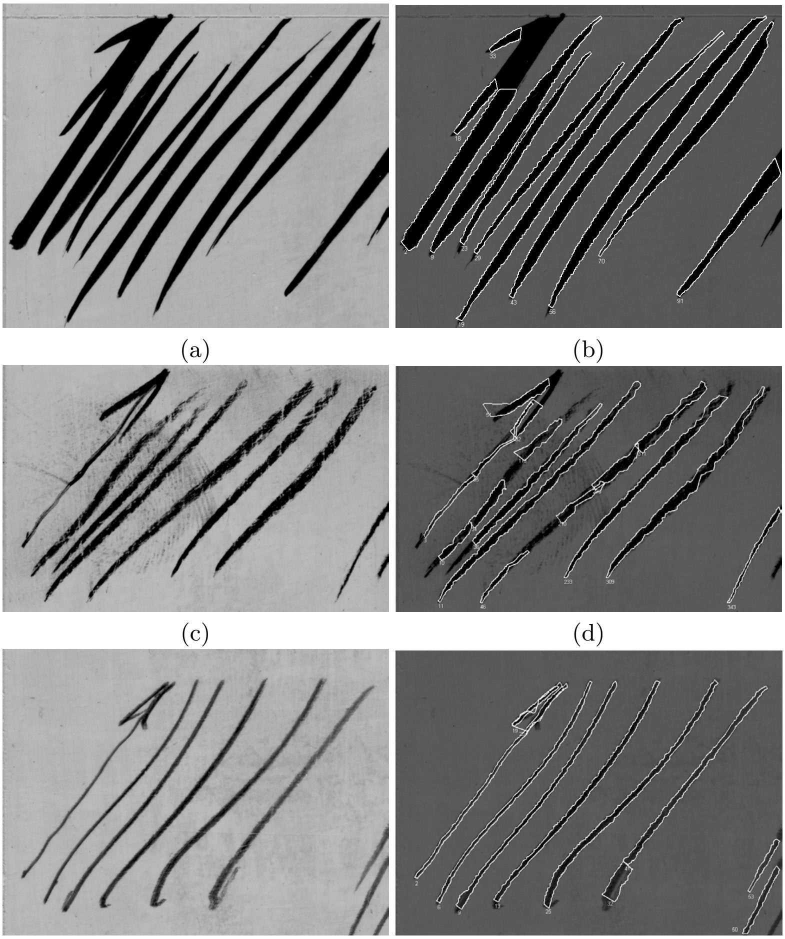
Fig. 3. Segmentation and Refinement (a) cross sections and polygonal boundary (b) edgels with axis and gray value profiles (c) initial "top" and "bottom" boundary boundary (d) converged "rigid" (black) and "non-rigid" snakes (white-dashed)

of strokes requires an approach that also incorporates boundary information [5]. We used Doermann's segmentation algorithm in the Segmentation part of our approach, since it provides both, the boundary of a stroke and intensity profiles, which will be used to characterize strokes. Figure 2 gives an overview of our approach consisting of three basic steps, segmentation, boundary refinement and feature extraction.

Segmentation. In the Step I, first edgels located at the stroke contour are detected by a Canny edge detector. Second, cross sections (perpendicular to the stroke boundary) are built as the connection form pairs of opposite edgels. To form a cross section the gradient vectors have to point to opposite directions. Finally, neighbored cross sections are linked into groups and represent a stroke segment. Figure 3(a) shows the cross sections grouped into one stroke segment and the polygonal boundary. For further algorithmic details of we refer to [1].

Boundary refinement. In Step II the approximation of the stroke boundary by a closed polygon is refined by "snakes", a method based on active contours [6]. After determining the principal component of the edgel distribution of a stroke segment, the contour is split into two sides ("top" and "bottom" boundary) that are treated separately. A set of gray value profiles, perpendicular to the axis, represent the domain for the snake algorithm. Figure 3(b) shows the equidistant profiles in the original image, and rearranged as an image (c). The snake moves through this domain to minimize an energy functional determined by inner parameters controlling rigidity and tension of the snake and an external energy influenced by a gradient vector flow in order to provide accurate and fast convergence to boundary concavities.

Feature extraction. Contour estimates with different levels of elasticity provide descriptive information by means of deviation against each other. We used two succeeding snakes. The first rigid snake was initialized on the coarse contour estimate. The second, more elastic snake proceeds from this position. MEAN of the deviation and standard deviation (SDV) of the deviation between the two snakes are used as descriptive features. For more details please refer to [7].

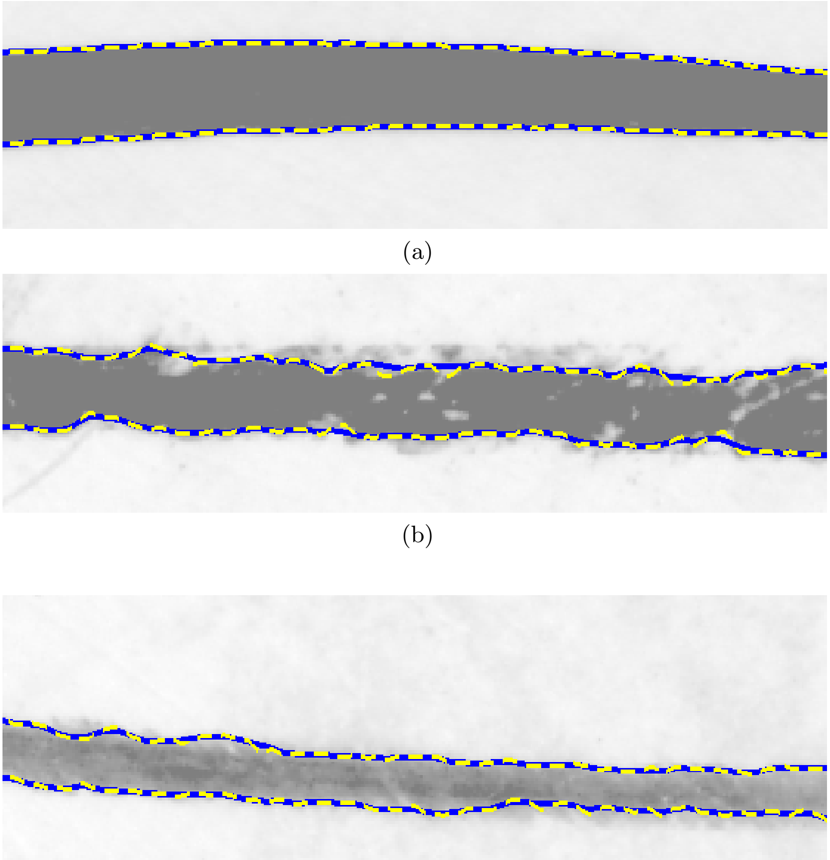


(a) (b) (c) (d) (e) (f)

Fig. 4. The left column shows details from the test panel with strokes used in our experiments: brush strokes (873x729 pixel) (a), chalk strokes (992x631 pixel)(c) and graphite strokes (989x729) pixel)(e). The right column shows the detected boundaries of the segmentation step (the original images are displayed darker for better illustration of the boundaries

4 Experimental Results and Discussion

In our experiments we studied the differences of three types of drawing tools – brush, chalk and graphite. Test panels (21cm x 30cm) containing sets of the mentioned strokes have been prepared by a restorer. The test panels were digitized using a flat-bed scanner with an optical resolution of 1200 dpi. Details from images, as depicted in Figure 4 have been cropped manually. Figure 4 (a) shows a series of brush strokes, (c) chalk strokes and (e) graphite strokes, all applied in bottom up direction.



(a)

(b)

(c)

Fig. 5. Details from the test panel showing stroke used in our experiments and the overlay of the snakes: brush strokes (a), chalk strokes (b) and graphite strokes (c).

The result of the segmentation step is illustrated in Figure 4 (b),(d) and (f) respectively. The boundary of the stroke segments, that consist of at least 20 cross sections are depicted. The segmentation algorithm works well for most of the brush strokes and graphite stokes. Problems arise e.g. at left stroke in Figure 4(a), which is not segmented completely, since the stroke width parameter was set to narrow. The segmentation algorithm, still has problems with overlapping strokes like the "arrow top " in the left most stroke of Figure 4(f) and (d). Problems occur with the chalk strokes in Figure 4(d) which are segmented into many small segments due to the inhomogeneity of the strokes. This necessitates a further processing step, that will be handled together with the overlapping problem.

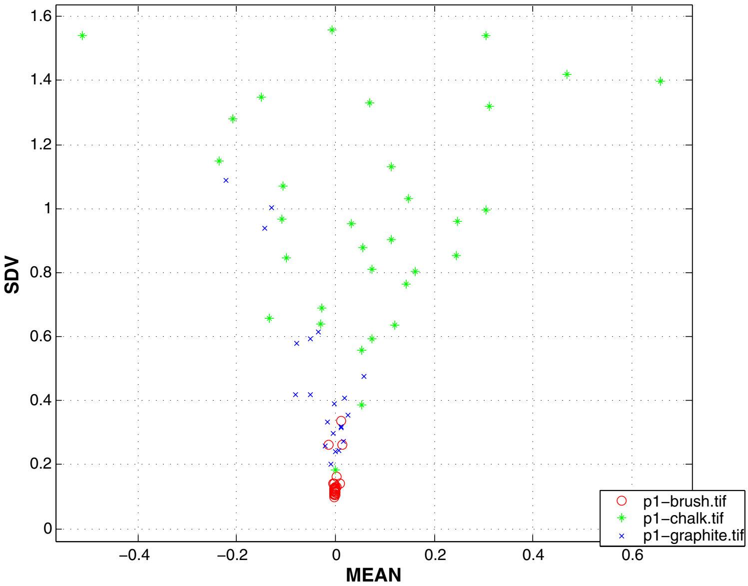


Fig. 6. Standard deviation (SDV) and MEAN of the snake deviations. The deviations are measured on the "top" and "bottom" boundary of the individual brush, chalk and graphite strokes.

For the refinement and feature extraction step, the stroke segments shown are used. First, the refinement step is initialized by the boundary of the segmentation step. The refinement algorithm, i.e. the adaptation of the two snakes with different rigidity, is applied separately to the "top" and "bottom" boundary of a stroke. Figure 5(a,b,c) shows three exemplary strokes together with an overlay of the more elastic (dotted bright line) and more rigid snake (underlying black line). It can be observed that the deviation of the rigid and elastic snake is smaller from the brush stroke then those from the black chalk and graphite strokes.

To show the differences calculated, the SDV- and MEAN-values of the deviations of the two snakes, i.e. two values, one for the "top" and one for the "bottom" boundary, are plotted in the diagram of Figure 6. The MEAN values of the brush strokes (denoted as circles) are concentrated near zero, while there is a higher variation of the MEAN graphite strokes (denoted as "x") and brush strokes (denoted as stars). Similarly, the standard deviation SDV of brush strokes is below 0.2 for all but two of the stroke borders. The SDV values for chalk and graphite is between 0.2 and 1.6 in our samples. So using the SDV feature will allow to distinguish between brush, i.e. a fluid drawing tool, and graphite and chalk respectively as dry drawing tools. Using a combination of SDV and MEAN the data of our samples can be used do differentiate between graphite and chalk, since most of the chalk values are positioned right and above the graphite values.

Still, this results are preliminary and experiments with more samples are necessary. Furthermore the reliability of this differentiation can be improved if a set of strokes is considered. As can be observed in underdrawings, certain regions of a drawing, a couple of strokes is applied with the same drawing tool, e.g. as hatches or cross hatches.

5 Conclusion and Outlook

The boundary analysis algorithm presented in this paper successfully detects and refines the boundary of strokes and extracts features that allow to differentiate between dry and fluid drawing tools. The first results showed, that the visual appearance of the boundary of a stroke can be used for discrimination. Still, further experiments with more samples are necessary to prove our method. The next steps will also incorporate additional features, like the texture of the different types of strokes, to get a measure for granularity of a stroke. Further we have noticed, that, in some cases, there is a difference between the "top" and "bottom" boundary of a stroke in dry drawing tools. This observation has to be proofed and evaluated. As reported, some problems occur in the segmentation step, if the strokes are interrupted. So one of our goals is to improve the robustness of the segmentation step and to extend the approach to segment overlapping and crossing stroke formations as e.g. reported in [8].

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