

# METHOD OF STROKE SEGMENTATION FOR HANDWRITTEN INPUT

## Background of the Invention

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### Field of the Invention

This invention relates generally to handwriting recognition, and more particularly to a method of stroke segmentation of handwritten input.

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### Description of the Prior Art

Machine recognition of human handwriting is a very difficult problem, and with the recent explosion of pen-based computing devices, has become an important problem to be addressed. There exist many very different approaches to this problem, but one useful approach has been to divide the writing into a sequence of fundamental movements, or "strokes", and use the strokes (which are parametrized in some way) as inputs to a stroke-based character recognizer.

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A key requirement in a stroke-based recognizer is that multiple instances of the same character class (e.g. the letter "A" written at different times and by different writers) should be divided into a similar set of strokes each time. This helps insure that recognition is not too difficult, because the description of the character instances will "look" similar to the character recognizer itself. In the ideal case, all instances of a given character would always contain the same number of strokes, the strokes would all be in the same relative locations, and the featural descriptions of the strokes would all be very similar across the instances. This ideal is not achievable in practice, but to the extent it can be approached, recognition accuracy can be improved.

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In one technique in the prior art, stroke boundaries are set at points where pen velocity in the vertical (or "y") direction is zero -- that is, at points where the writing begins moving upward, or begins moving downward. The resulting set of strokes may then be called "upstrokes" and "downstrokes". This method is discussed in Mermelstein & Eden, "Experiments on Computer Recognition of Connected Handwritten Words", in Information And Control vol. 7, pp. 255-270, 1964. One problem with this method is that it is overly sensitive to changes in the vertical direction, and not sensitive at all to changes in the horizontal direction. Yet many characters are composed of horizontal pieces -- for example, the cross of a "t" and the three prongs of an "E" are normally much more horizontal than vertical, even in sloppy writing. A y-velocity based stroke segmenter will sometimes break a horizontal piece into one stroke, but often it will be broken into two, three, or even many more, simply because of small jitters of the pen in the vertical direction. This leads to poor recognition accuracy, because multiple instances of the same character will often be segmented into different-looking sets of strokes. Attempts to correct the inaccuracies of this method, including requiring a minimum vertical direction change before creating a new stroke have had only limited success, and many of the same basic problems still remain.

In another existing technique, this problem is solved by setting the stroke boundaries at points where curvature is at a local maximum and exceeds some threshold value that corresponds to sharp bends in the writing. Since a sharp bend can occur regardless of the direction the pen is moving, this method is not sensitive to the orientation of the various parts of handwritten input, such as words or characters. However, the curvature-based technique has its own problems as well. Suppose, for example, a person writes an "L" with a very gradual bend, rather than a sharp bend, so that it starts to look more like a "C". The method might fail to segment the "L" in

this case if the threshold curvature required for stroke boundaries was not met. Simply lowering the threshold does not solve the problem, because this can simply lead to excessive numbers of strokes. Having too many extra strokes is just as bad as having too few, because again it means that multiple instances of the same character are often segmented into different types of strokes.

Accordingly a need exists for a stroke segmentation technique that is more accurate and not subject to the problems in the methods discussed, such as the y-velocity method and the existing curvature method.

### Summary of the Invention

Accordingly, the present invention provides a method of segmenting handwritten input into strokes which are consistent in number across multiple instances of each particular character class.

The present invention provides a method of segmenting handwritten input into strokes which are similar in shape and location across multiple instances of each particular character class of input.

Generally, the method of the present invention includes a step of calculating the derivative, or instantaneous rate of change, of the curvature at points in the handwritten input. The method then selects as stroke boundary points certain points (or pixels) in the input which lie between a point of high curvature derivative and a succeeding point of low curvature derivative. Such boundary points are not influenced by absolute curvature values, but rather only by relative changes in the curvature.

### Brief Description of the Drawings

FIG. 1 Illustrates a flow diagram of operation for identifying stroke boundaries in accordance with a preferred embodiment of the present invention.

FIG. 2 Illustrates segmentation into strokes of handwritten input produced by the y-velocity prior art method.

FIG. 3 Illustrates segmentation into strokes of handwritten input produced by the curvature prior art method.

FIG. 4 Illustrates segmentation into strokes of handwritten input produced by a preferred embodiment of the present invention.

FIG. 5 Illustrates points making up the letter "L" as received from a digitizing device.

FIG. 6 Illustrates points making up the letter "L" after resampling to a constant distance in accordance with a preferred embodiment of the present invention.

FIG. 7 Is an exploded view illustrating a curvature calculation of a preferred embodiment of the present invention.

FIG. 8 Illustrates graphically the curvature values calculated for each point in FIG. 7.

FIG. 9 Illustrates graphically the derivative of curvature values calculated for each point in FIG. 7.

### Detailed Description of the Preferred Embodiments

Typically, handwritten character input is collected from the user in the form of discrete continuous segments. A discrete continuous segment consists of one or more pen strokes, where a pen stroke is the mark left by a pen during its period of contact with an input device such as a digitizing tablet or paper.



In the present invention one or more discrete continuous segments are the units of handwritten input being segmented into strokes. Handwritten input is input which is captured electronically that includes but is not limited to the following:

5 handwritten input; electronic input; input captured through pressure, such as stamped input; input that is received electronically, such as via facsimile, pager, or other device.

A stroke is represented as a sequence of points sampled at approximately regular intervals by the input device. Each

10 point is described at minimum by an X and a Y coordinate. Strokes may be captured electronically using a digitizing tablet, or alternatively may be derived from a scanned or faxed image through a process of line detection in the image; such methods of capturing electronically are understood in the art. In a

15 preferred method handwritten input is accepted by a device, such as a personal digital assistant (PDA) or other device. Other devices that function to receive handwritten input include, but are not limited to, the following: computers, modems, pagers, telephones, digital televisions, interactive

20 televisions, devices having a digitizing tablet, facsimile devices, scanning devices, and other devices with the ability to capture handwritten input. Generally, when strokes are captured electronically, each point is represented by a pixel, such that a stroke is represented by a series of pixel on the device.

25 In accordance with the present invention, handwritten input maybe in the form of alphanumeric characters, ideographic characters or other forms of characters or symbols of written communication.

Referring now to the figures, FIGs. 2 and 3 illustrate

30 stroke segmentation of alphanumeric handwritten input with a high probability of inaccuracies in interpretation of the input when stroke segmentations are passed to a stroke-based recognizer. FIG. 2 illustrates stroke segmentation according to the y-velocity method (200). FIG. 3 illustrates stroke

35 segmentation according to the curvature method (300). FIG. 4

illustrates stroke segmentation of the same alphanumeric input of FIGs. 2 and 3 where the stroke segmentation is made in accordance with the teachings of the present invention (400) and such stroke segmentation has a high probability of accurate interpretation when passed to a stroke-based recognizer.

Referring now to FIG. 1, FIG. 1 illustrates a flowchart of a preferred method in accordance with the teachings of the present invention. Handwritten input from the digitizer or other device is received in the form of xy coordinates (110) (with associated penup or pendown states). Typically these points are represented by pixels. Generally, the present method resamples the handwritten input to obtain points which are equally spaced along the length of the handwritten input (120). Figure 5 illustrates an example of the letter "L" (500) as a series of points or pixels before resampling. Figure 6 illustrates the same letter "L" (600) as a series of points or pixels after resampling. Resampling is done using an interpoint distance  $d$  (610) that is constant throughout the handwritten input. Preferably, the value of  $d$  chosen is such that the median input height in the handwritten input is approximately in the range of 15 to 30 times  $d$ . For example, in FIG. 6 the value of  $d$  chosen is such that the median letter height in the word is approximately in the range of 15 to 30 times  $d$ .

The preferred embodiment of FIG. 1 calculates the curvature at each resampled point (130). Figure 7 illustrates graphically a depiction of the data for calculation of curvature at a point R (710). Curvature at a resampled point R (710) is defined as the distance to R's successor (point R+1 (730)) from a point P (720), obtained by projecting linearly from R's predecessor (R-1, (750)) through R itself. This distance is shown in Figure 7 as element 740. Curvature at endpoints of the handwritten input is defined as equal to that at the corresponding nearest neighbor points. Curvatures at the interior points of the handwritten input may also be computed

by projecting two points away from R, rather than one point (and using a point two points prior to R, rather than R-1), to obtain a more robust estimate. Figure 8 illustrates graphically the curvature values obtained for the points shown in Figure 7.

5       For example, the above mentioned example of an "L" with a gradual bend could be segmented into a vertical and a horizontal stroke as long as the two "straight" parts of the "L" were significantly straighter than the bend between them. The curvature would then be increasing going into the bend (i.e.,  
10   the curvature derivative would be high) and decreasing going away from the bend (the curvature derivative would be low), thus allowing a stroke boundary at or near the bend, as desired.

      In a preferred embodiment of the present invention, once  
15   the curvatures have been obtained for each resampled point, the array of curvatures for the resampled points may be smoothed to minimize any known artifacts introduced by the digitizing process. The type of smoothing to be performed should be a standard method which is selected based on the  
20   particular digitizing characteristics at hand. This might include averaging the value of a point with its neighbor points (weighting the point itself and nearest points higher), and replacing the curvature value of the point in question with the computed average. The size of the smoothing window used  
25   here should ideally be wider at low-curvature sections of the writing and narrower at high-curvature sections, to minimize loss of important information in the smoothing process. Since it is the curvature itself that is being smoothed, though, one preferable way to smooth is to compute initial curvatures,  
30   smooth based on those curvatures, and then re-smooth based on the new curvatures computed.

      In a preferred embodiment of the present invention, for each resampled point the absolute value of the curvature is computed by multiplying any negative curvature values by the  
35   value -1. Preferably the absolute values are used in computing



curvature derivatives, rather than the actual curvatures values, because the overall preferred embodiments of the present invention processes are only concerned with the sharpness of bends in the writing, and not which direction a given bend curves.

As illustrated in FIG. 1, the process next calculates the derivative of curvature at each resampled point (140). Referring to Figure 7, the derivative of curvature at point R is defined as the absolute value of curvature at point R+1 minus the absolute value of curvature at point R-1, divided by two (i.e., the slope of the curve of plotted curvature values). Figure 9 illustrates graphically the derivative of curvature obtained at each point shown in Figure 7. Similar to the use of more than two points to get a more accurate measure of curvature as described above, the derivative of curvature should be computed using a wider window (five points versus three) where the relevant points exist, and a narrower one (two points versus three) where necessary. Since the derivative of curvature cannot be calculated at the endpoints of the ink segment, the derivative of curvature at the endpoints is simply defined to be equal to that at the corresponding neighbor points.

Referring now to FIGs. 1 and 9, a preferred embodiment of the process next examines the newly calculated array of curvature derivative values to locate points where the derivative is at a local maximum (910) (defined to include points at the end of an inflection and about to decrease) or where the derivative is at a local minimum (920) (defined to include points at the end of an inflection and about to increase). For each section of input (in time) after a local maximum and before a local minimum, the midpoint of the section (in terms of arc length of the section) is located (930). This midpoint is defined as M. If the difference between the local maximum and the local minimum values for a section exceeds a threshold value T' (940), and the absolute curvature value at M (810)

exceeds some threshold value  $T''$  (820), the point M is selected as a stroke boundary (150).

5 The parameters  $T'$  and  $T''$  must be estimated and depend on the units in which curvature and curvature derivative are measured. There exact values are not critical as long as an error-tolerant character recognizer is used. In performing any experimental tuning of these or any other parameters for creating a specific embodiment of the invention, the desired goal is to attain segmentation which is as consistent as possible across multiple instances of particular character classes. This should be done empirically by examining how the procedure segments vary according to actual samples of the writing to be recognized.

10 In addition to the selected stroke boundary points described, points where the pen is lifted or put down are also selected as stroke boundary points. In a preferred embodiment of the present invention, curvature derivative-based boundary points maybe shifted by as much as two points to cause them to fall on points where absolute curvature value is maximal (160). By shifting the curvature derivative based boundary points, location of the stroke boundary points can be improved by making both the measure of curvature and the derivative of curvature yield the same stroke boundary. This preferred application of the present invention is only done for a given point if no stroke of less than three points will be produced, however.

25 The set of stroke boundary points in accordance with the present invention defines a set of corresponding strokes. These strokes can then be forwarded to a stroke-based character recognizer for recognition of the handwritten input.

30 The present invention and its preferred embodiments relate to novel, more accurate methods of stroke segmentation. In accordance with the present invention, in multiple instances of handwritten input the input is repeatedly divided into a similar set of strokes each time. For example, if the

handwritten input is the Letter "L" written at different times by different writers, the present invention and its preferred embodiments more accurately divide, each time, the input of the letter "L" into similar stroke segmentation boundary points  
5 regardless of the variances of the different writers. Such stroke segmentation aids in providing more accurate interpretation by a stroke-based recognizer.

Those skilled in the art will find many embodiments of the present invention to be useful. One obvious extension is  
10 from the case of printed handwriting described here to that of cursive writing. The actual method of segmentation of strokes is independent of the method of segmenting characters, and thus techniques which allow processing of cursive writing may readily make use of the stroke segmentation process described  
15 here. Another embodiment would be the segmentation of scanned, or "off-line" writing, into strokes. A straightforward way of applying the present invention to such a task would be to perform thinning of the writing to obtain a constant-width ink curve. Stroke boundaries could then be set at both  
20 curvature derivative-based points and at intersection points, since the lack of temporal information makes intersections and touching bends look similar.

It will be apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and  
25 may assume many embodiments other than the preferred forms particularly set out and described above. Accordingly, it is intended by the appended claims to cover all modifications of the invention that fall within that fall within the true spirit and scope of the invention and its equivalents.

## WHAT IS CLAIMED IS:

1. A method of recognizing a handwritten character composed of a plurality of inked pixels, comprising the steps of:
  - 5 calculating a curvature derivative value for each of a plurality of the inked pixels, whereby each curvature derivative value represents the rate of change of absolute curvature at the corresponding pixel,
  - selecting a set of stroke boundaries, such that each
  - 10 stroke boundary lies between an inked pixel with a high curvature derivative value and a succeeding inked pixel with a low curvature derivative value,
  - locating a set of strokes, such that each stroke boundary is located at the end of a stroke,
  - 15 calculating at least one stroke feature value for each stroke to produce a character feature set,
  - using the character feature set to determine the identity of said handwritten character.

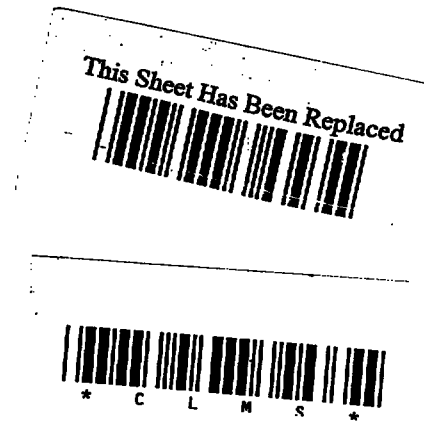
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2. The method of Claim 1 wherein the inked pixel with a high curvature derivative value has a locally maximal curvature derivative value, and the succeeding inked pixel with a low curvature derivative value has a locally minimal curvature derivative value.

3. The method of Claim 2 wherein each stroke boundary lies on a point midway between the inked pixel with locally maximal curvature derivative value and the inked pixel with locally minimal curvature derivative value.

4. The method of Claim 1 wherein each stroke boundary lies on a point of locally maximal absolute curvature value.



5. A method of recognizing a handwritten character composed of a sequence of points, each point comprising three spatial coordinate values, comprising the steps of:

5 calculating a curvature derivative value for each of a plurality of the points, whereby each curvature derivative value represents the rate of change of absolute curvature at the corresponding point,

10 selecting a set of stroke boundaries, such that each stroke boundary lies between a point with a high curvature derivative value and a succeeding point with a low curvature derivative value,

locating a set of strokes, such that each stroke boundary is located at the end of a stroke,

15 calculating at least one stroke feature value for each stroke to produce a character feature set,

using the character feature set to determine the identity of said handwritten character.

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6. The method of Claim 5 wherein the point with a high curvature derivative value has a locally maximal curvature derivative value, and the succeeding point with a low curvature derivative value has a locally minimal curvature derivative value.

7. The method of Claim 6 wherein each stroke boundary lies on a point midway between the point with locally maximal curvature derivative value and the point with locally minimal curvature derivative value.

8. The method of Claim 5 wherein each stroke boundary lies on a point of locally maximal absolute curvature value.

