Recognition of On-Line Handwritten Patterns Through Shape Metamorphosis

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Abstract

A novel method that recognizes on-line handwritten patterns (typical in pen-based computing applications) is proposed. The method combines the advantages of both global and local recognition methods, works in real-time, and avoids the use of statistical models that require extensive user data. It is also one of the first methods that handles collectively cursive words, and hand-drawn line figures. The proposed system achieves pattern recognition through the use of shape metamorphosis. It is based on the premise that if two shapes are similar they don't have to undergo a substantial metamorphosis process in order for one to assume the shape of the other. In other words, the "degree of morphing" becomes the primary matching criterion. The notion of the "degree of morphing" is quantified through an energy minimization approach. The potential of the method is highlighted by a set of experiments.

1 Introduction

The recognition of handwritten patterns like cursive script and line drawings, is an open research area with far-reaching applications [10]. A particular application area of relevance that has a high technological impact nowadays is the on-line recognition of handwritten words and line drawings [19]. This is due to the ever increasing spread of pen-based computing and its gradual establishment as an alternative or as a complement to the classical keyboard. Pen-based computing, ultimately, calls for robust and accurate recognition of cursive script and hand-drawn line figures that is beyond the capabilities of current algorithms and technologies.

This paper introduces a framework for handling collectively on-line handwritten patterns. It proposes the use of physics-based shape metamorphosis as a potentially powerful way of dealing with the recognition of difficult on-line patterns. Shape metamorphosis is a well established graphics technique [9, 16] that refers to the problem of computing a continuous shape transformation from an initial shape to a target shape. It has widespread applications in computer animation, but it is the first time (to the best of our knowledge) it is used for recognition purposes. The proposed system uses to its advantage the intuitive fact that two shapes that are quite similar don't have to go through an extensive metamorphosis process in order for each one to assume the shape of the other. Thus, the *degree of morphing* between a test pattern and a reference pattern becomes the primary matching criterion. The *degree of morphing* is an abstract quality that in our system is substantiated through a physics-based approach to shape metamorphosis (first proposed by T. W. Sederberg *et al.* [16]). Sederberg's approach was developed for animation purposes and it has been suitably modified to deal with the pattern recognition task at hand.

This is one of the first attempts to address the problem of difficult on-line handwritten patterns in a comprehensive way. Researchers have so far treated the various areas (handled collectively in the present approach), separately. Thus, there are separate methods for on-line cursive script recognition [3, 4, 5, 8, 12, 15, 17, 18] and on-line hand-drawn line figure recognition [11]. Broadly speaking, however, these methods work either at the global or the local level in the shape. The proposed approach is a hybrid method that combines the advantages of both the global and the local methods.

The organization of the paper is as follows: Section 2 presents some previous work conducted in the area and

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compares it to the proposed method. Section 3 gives an overview of the experimental setup and the various processing modules that comprise the system. The preprocessing phase is described in Section 4. In Section 5 the segmentation algorithm is explained. Section 6 unveils the shape metamorphosis method and its use in the pattern recognition context. In Section 7 the results from experimental tests are presented and are discussed. Finally, in Section 8 the paper is summarized, conclusions are drawn, and the future work is outlined.

2 Previous Work

On-line handwriting recognition is difficult in general due to the highly variable nature of the handwritten patterns. On-line cursive script recognition is particularly difficult because several characters can be written with a single stroke. Most methods for on-line cursive script recognition operate on word units. Most of these break a word into subparts. Such methods could be characterized as local methods [5, 8, 18]. In contrast, few methods follow the whole-word approach that leaves the words intact and avoids the segmentation problem entirely. Such methods could be characterized as global methods [3, 4].

The proposed metamorphosis-based recognition approach is a hybrid approach (both local and global). The main idea of the method is that it treats the cursive word as a curve and analyzes it at a local level through an appropriate segmentation algorithm. There is, however, a significant departure from the mainstream segmentation philosophy followed in such cases. The segmentation algorithm does not attempt to locate letters or parts of letters. In contrast, it performs robustly the significantly easier task of locating high curvature points (corners) and some low curvature points (key flat points). Thanks to this approach, the method can successfully and uniformly treat not only cursive words, but also hand-drawn line figures. The other important innovation of the method is that it uses the local information gathered from the segmentation process not to recognize individual characters but to produce an energy measure that is of a cumulative global character. This way, the method can account for co-articulation. Also, local variability of detrimental nature is smoothed out because its contribution to the global measure is not of sufficient strength. An example of such detrimental variability is the case of a retrograde stroke that appears sometimes in the writing of a letter. This sort of variability is very difficult to be handled at the local level alone where its effect may look dominant. Finally, the proposed method operates in real-time and precludes the use of an elaborate statistical approach that requires extensive user data [12, 17].

3 Outline of the System

The proposed method consists of three modules (see Fig. 1): Shape Sampling and Preprocessing, Shape Segmentation, and Shape Metamorphosis.

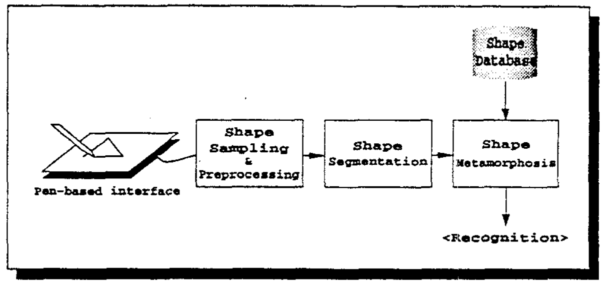

Figure 1: Metamorphosis-based shape recognition system.

The experimental setup in which the above method is implemented consists of a graphics workstation (SGI Indigo$^{TM}R4000$) and a graphics tablet (WACOM $UD-0608R$) that features an inking stylus. The inking stylus creates an environment for the user that is very much like the traditional pen and paper handwriting environment.

4 Shape Sampling and Preprocessing

The user writes or draws using the pressure sensitive inking stylus of the WACOM tablet. The handwritten shape is sampled at a maximum report rate of 140 points/second, a satisfactory sampling frequency for even the fastest handwriter. For the purposes of the present system, only the coordinates reported by the digitizer over time are used. The pressure data reported by the tablet go unused.

The sampled data undergo a simple smoothing operation. Smoothing helps to reduce the noise in the loci of pen-point movement obtained by a data tablet. The smoothing technique adopted is that suggested by H. Arakawa in [1].

The final part of the preprocessing is the performance of an orientation and size normalization. The orientation normalization is based on the work reported in [6].

5 Shape Segmentation

Metamorphosis between two shapes takes place at the point level. Points from the initial shape should be corresponded with points from the target shape. It would be computationally inefficient for all the shape points to participate in the metamorphosis process. It would also prove harmful to the recognition process due to the highly variable nature of the handwritten patterns. The ever present minuscule variations at the point level of the pattern, call for a level of abstraction that can be conveniently provided by a good segmentation algorithm.

A full account of the segmentation algorithm we propose and a comparative study that highlights its optimal qualities can be found in [14]. In short, the algorithm uses the method suggested by Brault *et al.* [2], slightly modified, to find the corners. The modification introduced renders the algorithm parameterless. Then, innovatively, a method conjugate to that of locating corners is used to locate the key flat points. Figs. 2 and 3 give characteristic examples of the algorithm's performance. The points indicated by small squares are the corner points, the points indicated by small discs are the key flat points, and the points indicated by small circles are the beginning and the end of the on-line trace.

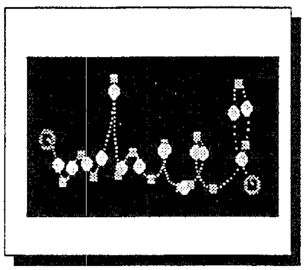

Figure 2: Segmentation of a cursive word by the proposed algorithm.

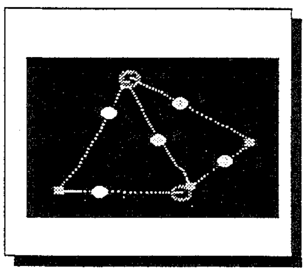

Figure 3: Segmentation of a hand-drawn shape by the proposed algorithm.

6 Shape Metamorphosis

Shape metamorphosis is defined as the transformation of one shape (initial) to another (target) [7, 16]. In our approach a shape is represented by its segmentation points. This representation is considered sufficient because the segmentation points of the shape serve as control points for an interpolating spline that produces the shape. If S_i $(i = 0, 1, \ldots, n)$ denote the segmentation points of the shape S, then the shape S could be represented in vector form as

$$\mathbf{S} = [S_0, S_1, \ldots, S_n]. \tag{1}$$

Metamorphosis from an initial shape $\mathbf{S}^{initial}$ to a target shape $\mathbf{S}^{target}$ is accomplished by performing a linear interpolation between the corresponding segmentation points of the two shapes. This interpolation could be discretely timed to give a series of intermediate shapes. Typically, the initial and the target shapes do not have the same number of segmentation points and even if they do, a point correspondence will produce in general intermediate chaotic shapes [16]. By chaotic shapes here, we mean shapes that do not maintain the similar parts between the initial and the target shapes. Since we are trying to relate the *degree of morphing* with the similarity between the initial shape and the target shape, intermediate chaotic shapes are unacceptable. In fact, a way should be found so that similar parts of the shapes to be maintained throughout the metamorphosis. This way, an initial shape which is identical with a target shape will remain completely unmetamorphosed throughout the metamorphosis process signifying a perfect match. If the initial shape is similar but not identical to the target shape, then intermediate shapes should be almost imperceptibly different in-between shapes signifying a highly likely match. Fig. 4 shows the proposed system exhibiting the desired metamorphosis performance in the case of two similar hand-drawn triangles. Fig. 5 shows the same hand-drawn triangles as the two ends of a chaotic metamorphosis. This latter metamorphosis behavior has been produced because a random correspondence of the triangles' segmentation points has been utilized instead of the correspondence suggested by the proposed method. It is evident from Fig. 5 that the production of significantly deformed intermediate shapes in a case like this, leaves no room for intuitive connection between *degree of morphing* and shape similarity.

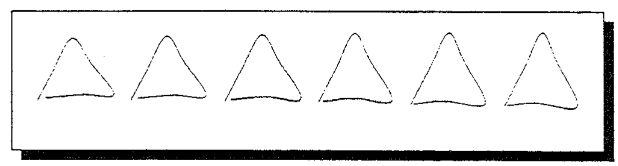

Figure 4: Non-chaotic metamorphosis of a triangle to a similar triangle.

Thus, the problem of shape metamorphosis for pattern recognition purposes is reduced to the following: first, where to insert new segmentation points so that the initial and the target shapes to have the same number of segmentation points; second, how to correspond the segmentation points in order to allow the *degree of morphing* to be linked to shape similarity. We have found that the physics-based approach to shape metamorphosis introduced by Sederberg *et al.* in [16] can

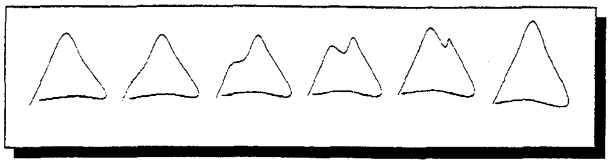

Figure 5: Chaotic metamorphosis of a triangle to a similar triangle.

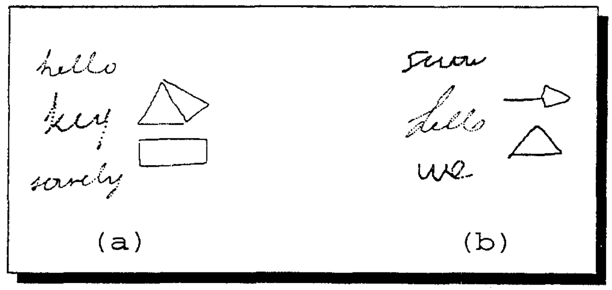

Figure 6: (a) Some typical cursive words and figures of user A recognized by the system. (b) Some typical cursive words and figures of user B recognized by the system.

successfully address the above issues if it is modified slightly. The idea proposed by Sederberg *et al.* was to model the initial ($\mathbf{S}^{initial}$) and the target ($\mathbf{S}^{target}$) shapes as pieces of wire made of some idealized metal. Then, metamorphosis from the initial wire shape to the target wire shape may take place through stretching and bending. The correspondence of segmentation points between the initial and the target shapes that yields the least amount of total energy expenditure is the one that is picked to drive the metamorphosis. Sederberg *et al.* used this minimum energy formulation to automate up to a certain degree the animation process and to produce visually pleasing results. Visually pleasing results are made possible because the method restricts angles from going to zero and avoids non-monotonic angle changes whenever possible. By restricting angles from going to zero the method avoids self-intersecting in-between shapes. By avoiding non-monotonic angle changes the method avoids in-between shapes like those shown in Fig. 5. These qualities, much to our interests, produce most of the time non-chaotic shape metamorphoses.

The modifications we introduced in the original method proposed by Sederberg *et al.* [16] were motivated by the necessity to guarantee the non-chaotic metamorphosis behavior in all cases, especially in the cases of similar initial and target shapes. In particular, the following two modifications have been made (see for details in [13]):

1. The ability for bending has been restricted.

2. The difference in the numbers of segmentation points between the initial shape and the target shape, has been introduced as an additional factor in the energy requirement of each metamorphosis.

7 Experimental Results

Two users have participated in the experiments. A reference database of one hundred cursive words, and ten hand-drawn line figures has been established from the first user (user A). Another reference database of sixty cursive words, and twelve hand-drawn line figures has been established from the second user (user B). For each shape in the reference databases, four test shapes have been collected at different days and times over a period of three months from the corresponding users (see Fig. 6). The test shapes from each user were matched against the corresponding reference database only (user-dependent system). The correct recognition rate of the system was perfect for both users (see Table 1).

Users	Ref. Patterns	Test Patterns	Total Score
A	110	440	100%
B	72	288	100%

Table 1: Test results.

Although the perfect performance of the system is impressive there is currently a serious limitation that should be taken into account. The system works only for singly connected shapes. That means that the pen should not be lifted during writing or drawing. This fact placed severe limitations in the experimentation process.

Despite the above limitations, the system exhibited superb behavior in cases that even human readers would have had difficulty recognizing the word. An example is given in Fig. 7 where the system successfully differentiates between a handwritten instance of the word *many* and a handwritten instance of the word *marry*. Additionally, the system achieved perfect performance with just a single reference shape per database item. It seems that due to the way the system works it can afford handling variability without encountering apriori examples.

8 Conclusions and Future Work

A novel method for the recognition of difficult on-line patterns such as cursive words and hand-drawn line

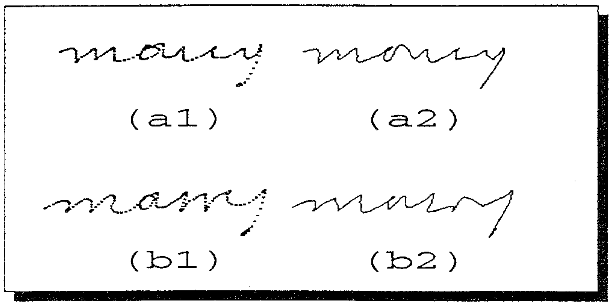

Figure 7: (a1) Handwritten instance of the word *many*. (a2) Spline representation of the instance in Fig. 7(a1). (b1) Handwritten instance of the word *marry*. (b2) Spline representation of the instance in Fig. 7(b1).

figures has been described. The on-line shapes are segmented into corner and key flat points. These points are used as control points for an interpolating spline to reproduce the shapes. A test spline shape is metamorphosed to each and every reference spline shape, through a physics-based minimum energy formulation. The specific formulation links the *degree of morphing* to shape similarity and allows the best match to be identified as the match that expended the least metamorphosis energy.

Currently, the weakest point of the method is that it works only for singly connected shapes. An algorithm is under development that will address this deficiency. Making the method work for disconnected shapes will enable the testing of the method with large dictionaries. In the present time, it is unknown if the method will scale-up in large dictionaries, although its perfect performance in the small testing dictionary is more than encouraging.

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