VISUALIZING CHANGES IN 2-D AND 3-D SHAPES

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ABSTRACT

Approximate shape comparison involves comparing two shapes which differ in some aspects, but share some similarities. Typical regions of shape difference result from image noise, occlusion, deformations, and affine transformations. This research presents a visual approach for relating shape difference using *Correlation Images*. A Correlation Image (CI) is a powerful mechanism for visualizing similarities and differences in ordered data by highlighting sequence data relationships using easily perceptible geometric shapes. The capabilities of four shape sequence representations, extracted from 2D contours of shapes and variants generated by various deformation processes, are explored for relating shape change using Correlation Images. In addition, a method to extend the technique to 3D shapes is presented.

1 INTRODUCTION

Approximate shape comparison, which involves comparison of two shapes which differ to some degree yet retain many key features in common, is an important area of research. For instance, monitoring bone deformations over time can be modeled as a problem of discovering how a shape has changed. This could lead to improved diagnosis of disease or increased confidence in a healing plan. Additional applications in diagnostic medicine, signature recognition, parts fitting problems, studies in the mapping of brain structure and function, and others could benefit from this research.

Shape matching and *shape monitoring* are two aspects of shape comparison. Shape matching can be viewed as a classification problem of comparing two or more shapes. Shape monitoring involves identifying and classifying differences between a pair of images or difference trends over a sequence of images. Some of the issues involved in shape comparison are matching shapes in noisy images, matching shapes with occlusions and deformations, handling affine transformations, automatic processing, and optimal performance. Traditional approaches to shape comparison are quantitative in nature, using structural or stochastic comparison techniques to arrive at a measure of similarity or difference in shapes [2, 5, 3]. These methods provide little insight into the types and locations of differences between the shapes.

Visualization techniques differ from quantitative techniques in that quantitative information is presented as pictures. Pictures convey qualitative information to the powerful pattern recognition capabilities of the human visual perception system. An estimated 50 percent of the brain's neurons are associated with vision. Visualization aims to put that neurological machinery to work. Comparing two N degree polynomials representing two shapes is significantly more difficult than comparing them visually side by side. However, visualization techniques lack the accuracy of quantitative techniques. Their most useful role is exploratory, highlighting anomalies, trends, similarities, and differences prior to performing detailed analysis.

This paper presents experimental results of comparing shapes using correlation images. Correlation images are a visualization method which can provide insight into relationships between sequences of data. In our experiments, moderately complex 2D test shapes, represented as sequences, were compared using Correlation Images. Several variants for each shape were generated which share most of the significant shape features as the samples, but have differences, such as local deformations and variations in location, orientation, scale, and boundary texture. The purpose of the experiments was to determine if Correlation Images can be used to accurately relate the location, type, and degree of shape change.

2 CORRELATION IMAGES

Correlation images provide a mechanism for visualizing patterns in data produced by exhaustive comparison of two sequences. Sequence comparisons are mapped to pixels on a 2D display and utilize the eye's ability to detect patterns in images. They are created by passing one sequence (floating) over the other (fixed) and comparing overlapping elements at each alignment. The comparisons resulting from each alignment are stored as a row of pixels in a correlation image. The comparison of individual sequence elements is a measure of their closeness of match, and is mapped to an intensity value. For viewing, pixels are colored depending on the intensity value stored. A powerful feature of correlation images is that sequence data relationships, such as partial matches, insertions, deletions, substitutions, expansions, contractions and transpositions, manifest themselves as clearly perceptible geometric shapes [1].

Several meaningful simple patterns manifest themselves on correlation images. Horizontal match lines result from consecutive sequence element comparisons in an alignment meeting a matching threshold. All other meaningful patterns are composed of configurations of horizontal match lines. Broken horizontal match lines indicate strong matching with regions of mismatch, or substitutions. Vertical and downward-diagonal lines are produced when each sequence has a repeating subsequence with the same element. Vertical lines result when the floating subsequence has fewer elements, or from expansions. Diagonal lines result when the fixed subsequence has fewer elements, or from contractions. Horizontal match lines with minor upward vertical shifting result from deletions. Horizontal match lines with minor downward vertical shifting result from insertions.

A more complex correlation image pattern is a periodic pattern. These result when sequences contain multiple copies of matching subsequences, and are common in some representations when handling symmetric shapes or common shape features, such as corners with the same angle. They produce multiple copies of any of the above patterns in different regions of the image.

3 SHAPE REPRESENTATIONS

Test shapes are represented using sequences constructed from boundary information. 1D shape descriptors, or sequences, are formed by tracing around contour boundaries and extracting boundary information at regular intervals. These intervals are small distances along the boundaries. Four shape descriptors are used. These are vertex coordinate, first derivative, second derivative and distance from vertex to centroid. Each representation has strengths and weaknesses in relating differing types of shape change using correlation images. Learning the capabilities of each representation can be used to guide future research in this area. The representations studied and the comparison metric used for corresponding sequence elements were:

Vertex Coordinates; the cartesian coordinates of evenly spaced boundary locations, using Euclidean distance.

First Derivative: the angle between consecutive vertex coordinates, using positive, normalized angular differences.

Second Derivative: the difference in angle between consecutive first derivatives, using the absolute value of the difference in values.

Centroid Distance: the radial distance from boundary vertex coordinates to the centroid, using the absolute value of the difference in values.

4 EXPERIMENTS

In order to test how correlation images can be used for relating shape change, a large number of case studies comparing contours of moderate complexity were constructed. Each case study involved a test contour with certain local features.

Some shapes contained relatively flat sides, while others had prominent rounded concave and convex features and sharp and rounded corners. Correlation images were produced from comparing each test contour to variants on it using each sequence representation. Each variant changed the shape in some manner, but retained the local features. The deformation operations used were, 1) a small random perturbation of boundary corner points, 2) random perturbation of all boundary points, 3) affine transformations for rotation, translation and scale, and 4) the introduction of a local indentation of varying size.

Shape comparison manifests itself as patterns on a correlation image. In some cases, simple CI patterns can be used to highlight subtle regions of similarity and difference. It is not the case that all CI patterns meaningfully depict shape change. In some cases, a representation may be ineffective in capturing information about a region of change. In these cases, some of the patterns produced are meaningless, which could potentially interfere with interpretation.

In order to guard against misinterpretation, exact CIs were produced. An exact CI is produced by comparing a test contour with itself. The patterns produced depict an exact match. In addition, approximate CIs were produced by comparing the test shapes to each variant. The measure of how well a given representation is at relating a shape change is measured by how well exact and approximate CI patterns resemble each other. In particular, an analysis of how the pattern change relates to the shape change was performed. It was expected that similar pattern changes would consistently manifest themselves in response to similar shape changes across all case studies. If this was not the case, the pattern change was discounted. The results of measuring whether a representation consistently produced predictable pattern changes corresponding to shape changes have been collected and tabulated in Table 1.

5 RESULTS AND CONCLUSIONS

Figure 1 shows one of the 2-D shapes tested and variations generated via perturbations and affine transformations. Figures 2 and 3 show the correlation images generated for each comparison (including the original shape to itself) using each of the representations.

No representation was found to successfully handle all shape changes studied. Some performed better in more cases than others, but each had its strengths and weaknesses. Vertex Coordinates were found to be most useful in the presence of boundary perturbation, provided no affine transformations were involved. First derivatives were found useful in identifying boundary perturbations if only the corner points changed, and was relatively unaffected by translation and scale change. Second derivatives were successful in all cases except when comparing

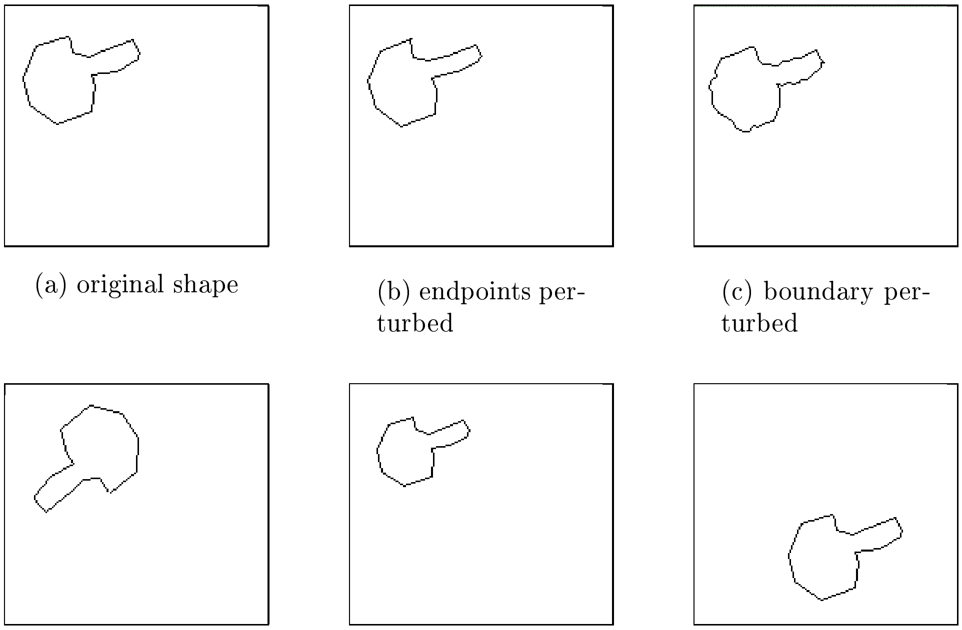
Shape Change	Success	Failure
No Indentation:		
Boundary Corner Perturbation	COORD,1D,2D,DTC	
Boundary Perturbation	COORD,DTC	1D,2D
Rotation	2D,DTC	COORD,1D
Translation	1D,2D,DTC	COORD
Scale	1D,2D	COORD,DTC
With Indentation:		
Boundary Corner Perturbation	COORD,1D,2D	DTC
Boundary Perturbation	COORD	1D,2D,DTC
Rotation	2D	COORD,1D,DTC
Translation	1D,2D	COORD,DTC
Scale	1D,2D	COORD,DTC

Table 1: Level of success for each shape representation in detection of various shape changes. COORD = coordinates, 1D = first derivative, 2D = second derivative, DTC = distance to centroid. Success means that structure caused by the given shape change was readily identified and classified in the resulting correlation image.

smooth and jaggy boundaries. All three of the above representations handled these changes even if local indentations of various sizes were introduced. Centroid distance works well on all cases except if a scale change is introduced. Also, centroid distance is the only representation which is significantly affected by the introduction of local indentations, as this results in offsetting the location of the centroid. Complete descriptions of experiments conducted can be found in [4].

The experimental results have demonstrated that correlation images can be used for approximate shape comparison. Moderately complex shape changes are shown to consistently correspond to simple correlation image pattern changes. This method is simple to understand and build upon and could be used in many shape comparison applications.

We have extended the work to three dimensions by creating composite sequences from adjacent 2-D slices of volumetric data. The major limitation of this approach is that it is only effective if the objects being compared share a common major axis. Results have been comparable to the 2-D experiments, and we are now examining other 3-D shape representations which overcome the previously mentioned limitation.



(a) original shape (b) endpoints perturbed (c) boundary perturbed

(d) rotated (e) scale change (f) translated

Figure 1: A moderately complex shape and several variants.

References

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[2] Gorman, J.W., Mitchell, O.R., Kuhl, F.P., "Partial Shape Recognition Using Dynamic Programming," IEEE Trans. Pattern Anal. Machine Intell., vol. 10, no. 2, Mar. 1988, pp. 257-266.

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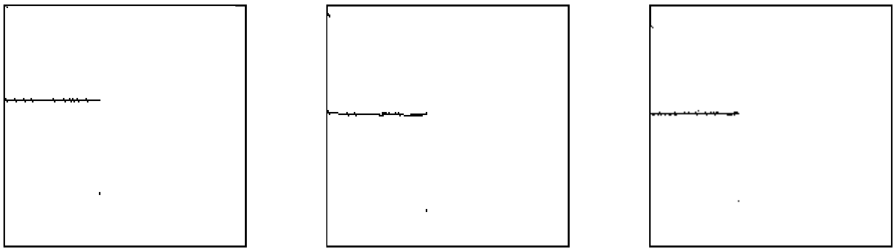
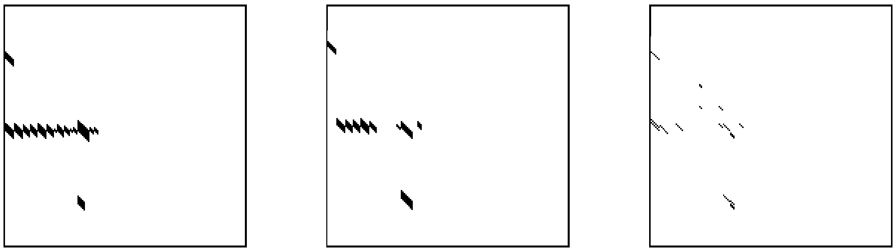
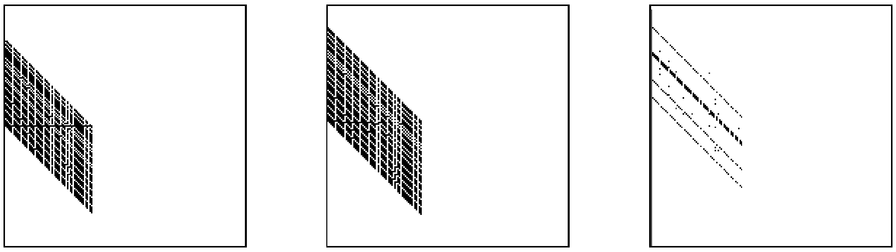


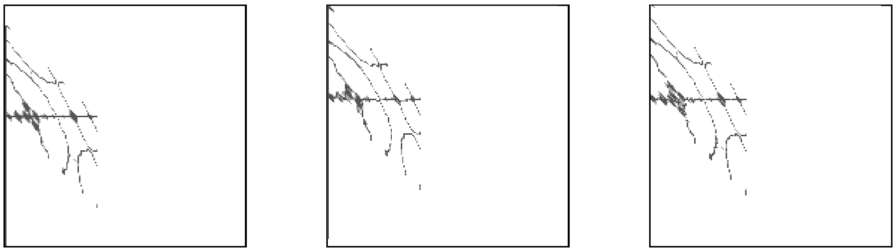
(a) against itself (coordinates) (b) endpoint perturbed (c) boundary perturbed



(d) against itself (1st derivative) (e) endpoint perturbed (f) boundary perturbed

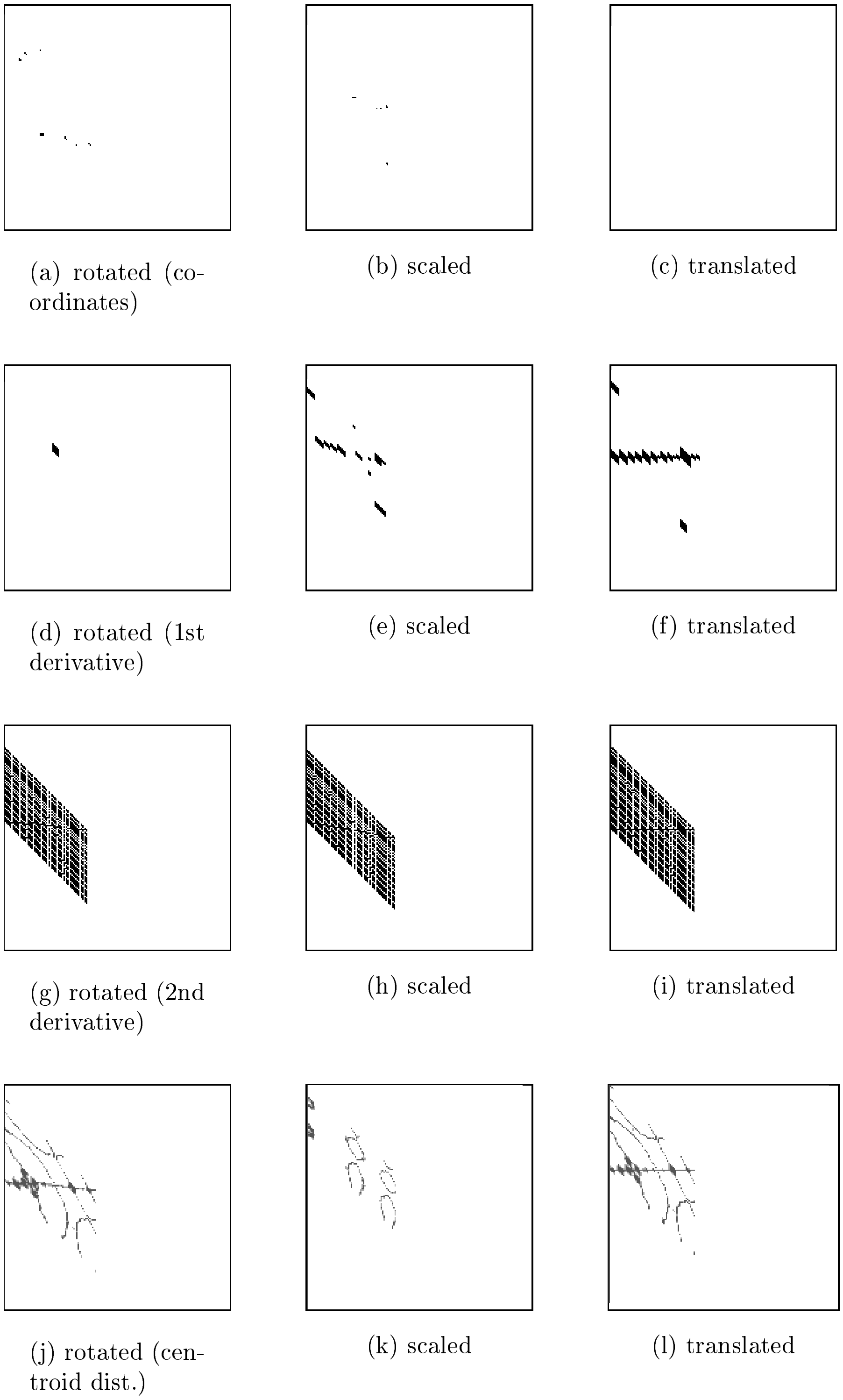


(g) against itself (2nd derivative) (h) endpoint perturbed (i) boundary perturbed



(j) against itself (centroid dist.) (k) endpoint perturbed (l) boundary perturbed

Figure 2: Correlation images created by comparing original shape against itself and variants generated by perturbations using various representations.



(a) rotated (co-ordinates)

(b) scaled

(c) translated

(d) rotated (1st derivative)

(e) scaled

(f) translated

(g) rotated (2nd derivative)

(h) scaled

(i) translated

(j) rotated (centroid dist.)

(k) scaled

(l) translated

Figure 3: Correlation images created by comparing original shape against variants generated by affine transformations using various representations.