Partial Shape Matching for CBIR of Spine X-ray Images

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ABSTRACT

Efficient content-based image retrieval (CBIR) of biomedical images is a challenging problem. Feature representation algorithms used in indexing medical images on the pathology of interest have to address conflicting goals of reducing feature dimensionality while retaining important and often subtle biomedical features. In case of the vertebra, its shape effectively describes various pathologies identified by medical experts as being consistently and reliably found in x-rays in the image collection. A suitable shape method must enable retrieval relevant to the pathology in question. An approach to enabling pathology based retrieval is to use partial shape matching techniques. This paper describes our research in the development of such methods and initial retrieval results and related issues. The research is a part of our ongoing effort in developing CBIR for digitized images of a collection of 17,000 cervical and lumbar spine x-rays taken as a part of the second National Health and Nutrition Examination Survey (NHANES II) at the Lister Hill National Center for Biomedical Communications, an intramural R&D division of the U.S. National Library of Medicine.

Keywords: Content-based Image Retrieval, Medical Image Databases, Partial Shape Matching, Procrustes Distance

1. INTRODUCTION

There has been growing research interest in developing content-based image retrieval (CBIR) methods for biomedical images.[1] However, due to the lack of effective automated methods, these images are typically annotated manually and retrieved using a text keyword-based search. Even such retrieval is impossible for collections of images that have not been annotated or indexed. CBIR methods developed specifically for biomedical images could offer a solution to such problems. However, CBIR of biomedical images is a challenging problem. Feature representation algorithms used in indexing medical images on the pathology of interest have to address conflicting goals of reducing feature dimensionality while retaining important and often subtle biomedical features. Additionally, the user is often interested in only a small region of interest, for example, anterior osteophytes (AO) in spine x-rays. In query-by-sketch and query-by-example paradigms of shape-based CBIR, the part of the shape not of interest often hinders retrieval precision. To address this drawback, we propose the use of *partial shape matching* methods in retrieving images of interest by allowing the user to only sketch or identify the region of interest on the vertebra boundary. This paper describes our initial work in partial shape matching as part of the broader research into CBIR of medical images, reported earlier.[2–4] We present the development of a partial shape matching method for fixed point boundary data, initial evaluation on a small set of vertebra shapes classified by a medical expert, and a discussion on the results. Work is in progress for sets with variable number of boundary points.

The Lister Hill National Center for Biomedical Communications, a research and development division of the U.S. National Library of Medicine (NLM), maintains a digital archive of 17,000 cervical and lumbar spine images collected in the second National Health and Nutrition Examination Survey (NHANES II) conducted by the National Center for Health Statistics (NCHS). Classification of the images for the osteoarthritis research

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community has been a long-standing goal of researchers at the NLM,[5] and collaborators at NCHS and the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS). Also, the capability to retrieve images based on geometric characteristics of the vertebral structures is of interest to the vertebral morphometry community. To address these goals, automated or computer-assisted classification and retrieval methods are highly desirable, since such methods offset the high cost of manual classification and manipulation by medical experts. Content experts have identified visual features of the images specifically related to osteoarthritis, but the images have never been manually indexed for these features, which include anterior osteophytes, disc space narrowing for the cervical and lumbar spine, subluxation for the cervical spine, and spondylolisthesis for the lumbar spine. We are investigating automated or computer-assisted methods that use image features for indexing and retrieval of these images.

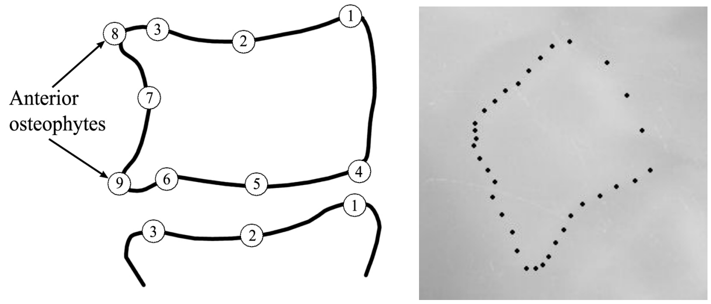
In our study of the spine x-rays, we observe that only shape features appear promising for indexing the images, since the images are gray scale and offer very little in terms of texture for the anatomy of interest. We have implemented a modular prototype system for content-based image retrieval for a subset of the spine x-rays and health survey text data associated with these x-rays.[2] The system supports retrieval based on shape similarity to a sketch or example vertebral image, as well as conventional text retrieval. Methods that are currently supported include those based on Fourier Descriptors[6] and Polygon Approximation.[7,8] These shape representation methods consider the entire vertebra boundary as a single object. Thus, queries must be made on the entire shape. Our experiments with biomedical expert users have revealed that users are often interested in locating images that express a pathology. In case of vertebrae, this is usually expressed in only a part of the boundary. The users tend to focus on that particular segment of the shape boundary in attempting to retrieve other similar images and disregard shape characteristics in other boundary regions. The shape similarity methods, however, match the entire boundary, often resulting in less than acceptable results.[3,4] We believe that partial or incomplete shape matching may be necessary to compensate for problems posed by whole-to-whole shape matching. This paper describes initial efforts in developing such a method. We also present initial efforts in addressing the difficult problem of evaluating the performance of partial shape matching (PSM) algorithms when applied to vertebra shapes.

The paper is organized as follows. Section 2 presents a brief overview of PSM methods and PSM application to vertebra shapes. Section 3 describes the PSM method that we developed. Section 4 details the performance evaluation method. Section 5 presents the results and analysis. We conclude with Section 6 wherein we list our continuing and future work.

2. BACKGROUND

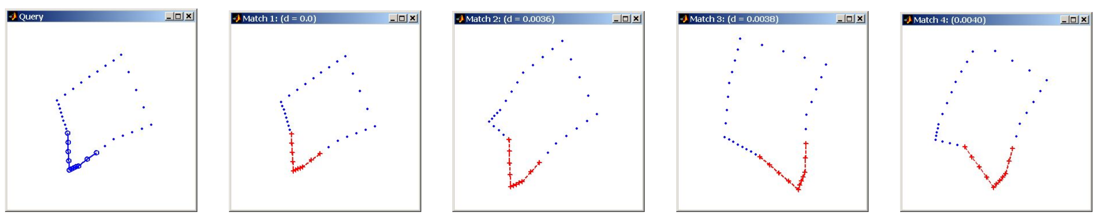
There is little in the literature about incomplete or partial shape matching or recognizing occluded objects. However, a recent contribution by Petrakis et al[9] presents an approach for open shape matching using Dynamic Programming (DP). Inflection points on the boundary serve as inputs to the shape representation method. The extracted shape features are length, area and rotation angle. The approach is matching of merged sequences of consecutive small segments in a shape with larger segments of another shape with an associated merging cost. DP selects the most promising merges and searches for the least cost match path from a table. Another approach by Mori et al[10] also employs DP as the partial shape matching method. They propose wedge wave feature extraction. The features are based on wedge wave convexity which consists of four factors: location on the contour, direction at which the contour is facing, scale of convexity and class of convexity (sharp or dull). Partial matching is enabled by extending DP matching to allow one-to-zero correspondence as well as one-to-one correspondence. The costs associated with one-to-zero correspondence share the same mechanism as the merging cost in the previous literature.[9]

In the NHANES II collection of digitized spine x-rays, medical experts have determined anterior osteophytes (AO) to be one of the pathologies that can be reliably and consistently detected in the set. AO are protrusions or bony growths along the anterior edge of the vertebra and can be found in the superior (upper) or inferior (lower) junctions with the discs. These regions can are between points 2-3-8-7, for the anterior superior osteophyte, and points 7-9-6-5 for the anterior inferior osteophyte as illustrated in Figure 1 (a). It is the goal of this research to enable retrieval by querying on this pathology. A sample retrieval is shown in Figure 2.



(a) (b)

Figure 1. (a) Illustration of 9-point model, (b) Image with 34 points superimposed.



(a) Query (b) d=0.0 (c) d=0.0036 (d) d=0.0038 (e) d=0.0040

Figure 2. An example of partial shape matching of anterior-inferior osteophyte using Procrustes distance. (a) Query shape, (b)-(e) Top 4 matches with normalized *dissimilarity* distances.

3. METHOD

In this paper we describe the development of a PSM method applicable to shapes described with a fixed number of points. The method is based on the Procrustes Distance model. The approach is to allows the user to select a region of interest along the vertebra boundary as shown in Figure 3. The selected partial shape is then matched using the Procrustes similarity metric with every other region in the shape. The regions from the shapes are then listed in decreasing order of similarity.

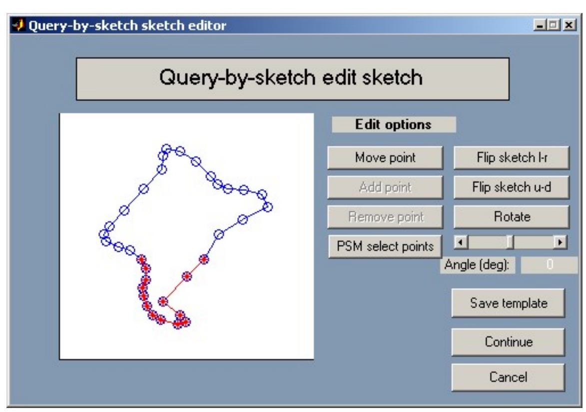


Figure 3. Selecting region of interest on the query shape.

Since the Procrustes matching process does point-to-point match, it requires the same number of points on both partial shapes, viz., the user selected query shape and the part of the database shape currently under consideration. Using a fixed point description of the vertebra boundary helps meet this condition. The Procrustes distance method then performs a linear transformation on one shape to find the best match between two shapes. This is represented by Equation 1, where (x, y) and (x', y') are n boundary point coordinates of shapes X and X'.

$$P = \sum_{i=1}^{n} \left| \begin{bmatrix} S \cdot \cos\theta & -\sin\theta & T_x \\ \sin\theta & S \cdot \cos\theta & T_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}_X - \begin{bmatrix} x'_i \\ y'_i \\ 1 \end{bmatrix}_{X'} \right|^2 \tag{1}$$

The matching process translates shape X by (Tx, Ty) such that the center of gravity of the two shapes coincide. Next, the shape X is scaled by S and rotated by θ for the minimum sum of squared distances between the boundary points of the two shapes. The $-$ sign indicates the Euclidean distance measure between two 2D points. In the context of shape space theory, this method finds the closest chord distance between two shapes.

4. EVALUATING PERFORMANCE

In this section we describe the method adopted to evaluate the performance of PSM for vertebra retrieval. This is especially challenging since the premise for developing the PSM algorithm is to close the gap between the user query on a specific pathology and retrieved results. Details of the performance evaluation setup and other issues are discussed below.

4.1. Data and Ground Truth

The data set consists of 93 segmented vertebrae composed of 57 cervical and 36 lumbar vertebrae. Each vertebra shape is described with 34 boundary points. Further, the vertebrae are grouped as normal and abnormal and on by degree of pathology. Anterior osteophytes are graded into 5 levels of severity, viz. Normal, 0, 1, 2 and 3. They are found both in cervical and lumbar vertebrae and on the superior and inferior regions of the boundary. Each vertebra could exhibit more than one pathology. 93 vertebrae are then grouped into 9 sets as shown in Table 1 below. These are then further divided by vertebra type, cervical and lumbar. Each group has approximately 20 vertebra.

Anterior Inferior:	Grade 0	Grade 1	Grade 2	Grade3
Anterior Superior:	Grade 0	Grade 1	Grade 2	Grade3
Normal	-	-	-	-

Table 1. Vertebra groups for evaluation. For this study, Normal vertebrae are considered distinct from vertebrae with Grade 0 Anterior Osteophytes.

Vertebrae were assigned these groups by a medical expert. However, caution must be adopted in utilizing this set as a *ground truth*. As with any medical diagnosis, the classification must be considered as an opinion. Multiple expert based development of ground truth must be adopted. Development of such a ground truth is a goal for us. We are using this limited set to explore and validate further development of the PSM approach to CBIR.

Queries The medical expert also developed a set of queries for each classification type described above. The query shapes were taken from the NHANES II data set. A total of 24 queries were developed; 4 instances of Normal, 7 of Grade 0, 6 each of Grade 1, and Grade 2, respectively, and 1 of Grade 3. The queries were then made on inferior and superior regions of AO as indicated by the medical expert. (Note: in this study normal vertebrae were considered distinct from vertebrae with Grade 0 Anterior Osteophytes in the classification made by the medical expert. In other work, such as our development of the digital spine atlas,[1] experts have used a 0-3 scale for AO with 0 being normal.)

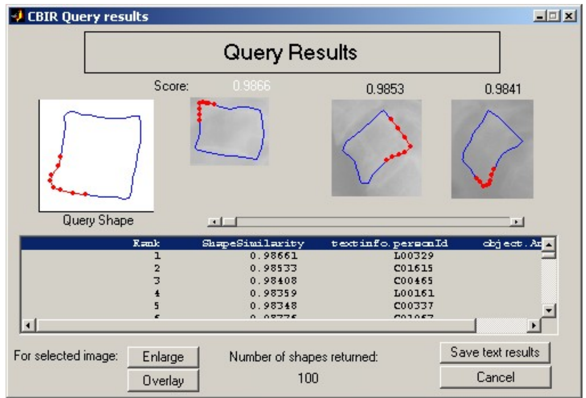


Figure 4. PSM query returns best match from entire vertebra shape.

4.2. Evaluation Approach

Two issues must be taken into consideration in developing a performance evaluation strategy.

1. Even though the classification is available for anterior superior and anterior inferior locations of the osteophytes, the current form of the PSM algorithm queries all possible sets of points on the entire shape. The method does not query just the anterior region, and could also return matches from the posterior region. This is illustrated in a real query made on an grade 0 anterior inferior osteophyte on the third lumbar vertebra (L3), shown in Figure 4. For this reason, this classification in the vertebrae marked as having anterior superior and anterior inferior osteophytes in the ground truth is ignored and the lists are merged.

2. Since the ground-truth/opinion set size is very small, lumbar and cervical vertebra are queried simultaneously. This classification is also ignored.

The evaluation approach is to study the top 10 matching (partial) shapes from each query. The results are presented as raw matches for each particular grade and with neighboring grade matches included. The groups are considered in increasing order of severity. This approach is considered acceptable since the opinion between medical experts often differs in close cases between grades. The goal is to reach a high raw match score as well as a sufficiently high score for neighboring grades. For example, on a normal vertebra query, a Grade 0 retrieval would be considered acceptable, since there is very small difference between two cases, and a researcher might not mind seeing this mix. For the same query, however, matches from higher grades is considered a false positive. Similarly, for a query on grade 1 vertebra, grade 0 and 2 are considered acceptable. The entire list of acceptable groups is shown in Table 2

Query	Acceptable Matches
Normal	Normal, Grade 0
Grade 0	Normal, Grade 0, Grade 1
Grade 1	Grade 0, Grade 1, Grade 2
Grade 2	Grade 1, Grade 2, Grade 3
Grade 3	Grade 2, Grade 3

Table 2. Matching grades

5. RESULTS AND ANALYSIS

We present the results in Table 3. The results are averaged over the number of queries. Individual results are shown in Figure 5. As can be seen, PSM improves over whole shape matching. The improvement in relevant

	Normal	Grade 0	Grade 1	Grade 2	Grade 3
Only Query Grade Type	1.25	5.43	2.83	5.00	2.00
Neighboring Grades Included	3.00	8.00	8.50	8.00	8.00
Whole Shape Matching	1.00	1.64	1.58	1.08	4.00

Table 3. Results averaged over number of queries for each grade.

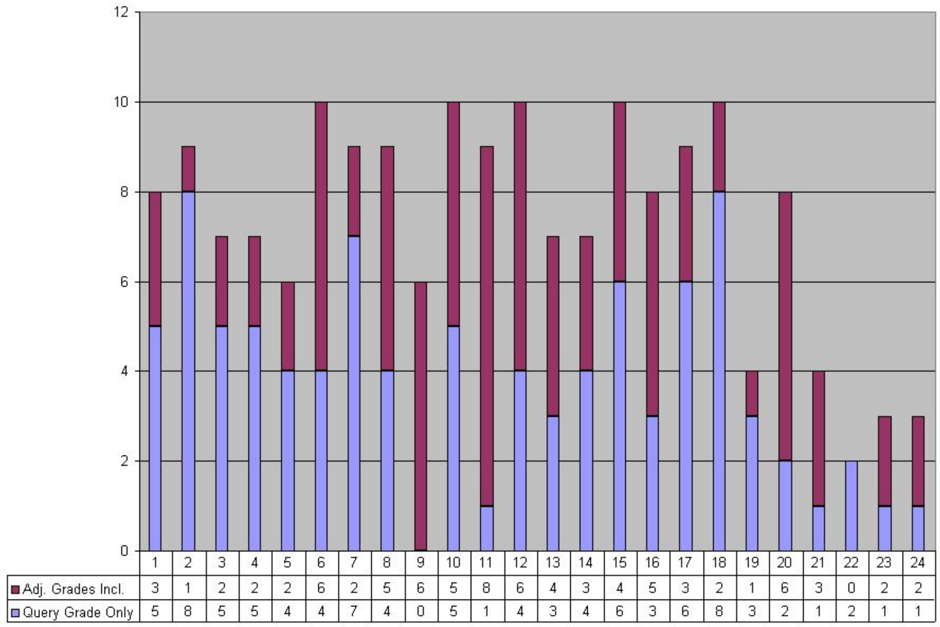


Figure 5. Individual query results and distribution of shapes of neighboring grades in retrieval.

retrieval is further improved if neighboring grade types are considered as close matches.

The chart in Figure 5 shows the proportion of shapes from adjacent grades on a given retrieval. Except in case of a few queries, PSM is able to retrieve many relevant shapes. Example retrieval images from these are shown in Figure 6. Analysis of the results revealed that two factors played an important role in the retrieval quality. The first, lack of control on the position of the partial query shape, i.e., if the user has specified the lower anterior region, any other "best" matching region can be returned. This is seen in the example in Figure 6 (b) and (c). The second factor is the number of points selected to represent the feature. This especially affects "generic" features such as corners. This is the reason why "normal" vertebrae shapes have shown such poor retrieval. Examples are seen in Figure 7 (a) and (b). In general, the Procrustes Distance based method, though fairly robust, is susceptible to minor factors such as number of points in the partial shape, and shape characteristics.

6. CONCLUSIONS AND FUTURE WORK

We have presented our initial work in developing and evaluating a partial shape matching algorithm for CBIR of vertebra shapes. The above evaluation has yielded promising results from PSM and pointed to the need for further work on the topic. Although major factors affecting results are clearly identifiable, it is still unclear how these factors work in conjunction with boundary characteristics and the algorithm. An important issue that surfaced in this study is the need for a standardized ground-truth data set that can be used to evaluate the methods. The ground truth set should be developed from multiple expert input and suitably combined. Additionally, the evaluation results must be validated by a number of medical experts to minimize the effect

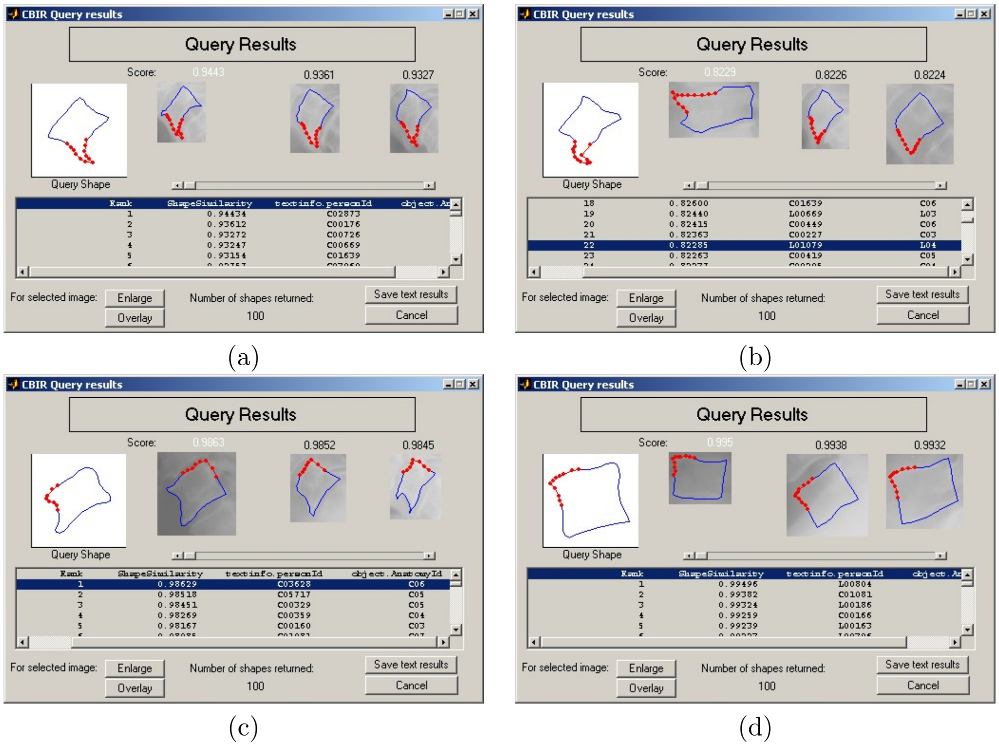


Figure 6. Examples of partial shape matching of AO using Procrustes distance.

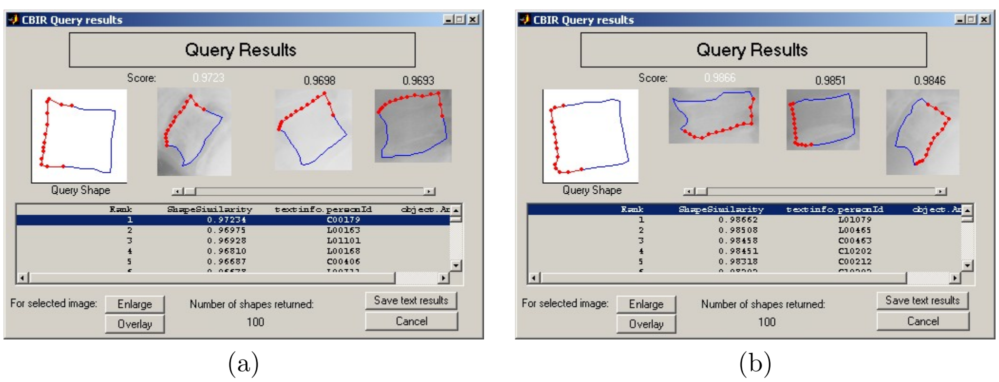


Figure 7. Examples of partial shape matching of normal vertebrae using Procrustes distance.

of inter- and intra-observer variability. Our work in this area and further development of shape algorithms is continuing as a part of a larger framework of developing CBIR for medical images.

REFERENCES

1. L. R. Long, S. Antani, D. J. Lee, D. M. Krainak, and G. R. Thoma, "Biomedical information from a national collection of spine x-rays: film to content-based retrieval," in *Proceedings of IS&T/SPIE Medical Imaging 2003: PACS and Integrated Medical Systems, Vol. SPIE 5033*, (San Diego, CA), February 2003.
2. S. Antani, L. R. Long, and G. R. Thoma, "A biomedical information system for combined content-based retrieval of spine x-ray images and associated text information," in *Proceedings of the Indian Conference on Computer Vision, Graphics, and Image Processing*, pp. 242–247, 2002.

3. S. Antani, L. R. Long, G. Thoma, and D. J. Lee, "Evaluation of shape indexing methods for content-based retrieval of x-ray images," in *Proceedings of IS&T/SPIE Conference on Storage and Retrieval for Media Databases 2003, Vol. SPIE 5021*, pp. 405–416, (Santa Clara, CA), January 2003.
4. S. Antani, D. Lee, L. Long, and G. R. Thoma, "Evaluation of shape similarity measurement methods for spine x-ray images," *Journal of Visual Communications and Image Representation* , Accepted for publication.
5. L. R. Long and G. R. Thoma, "Landmarking and feature localization in spine x-rays," *Journal of Electronic Imaging* **10**(4), pp. 939–956, 2001.
6. C. Zahn and R. Roskie, "Fourier descriptors for plane closed curves," *IEEE Computer* **C-21**(3), pp. 269–281, 1972.
7. D. Lee, S. Antani, and L. R. Long, "Similarity measurement using polygon curve representation and fourier descriptors for shape-based vertebral image retrieval.," in *Proceedings of IS&T/SPIE Medical Imaging 2003: Image Processing, Vol. SPIE 5032*, pp. 1283–1291, (San Diego, CA), February 2003.
8. X. Xu, D. Lee, A. S., and L. Long, "Localizing contour points for indexin an x-ray image retrieval system," in *Proc.* 16^{th} *IEEE Symposium on Computer-Based Medical Systems*, pp. 169–174, (New York, NY), 2003.
9. E. Petrakis, A. Diplaros, and E. Milios, "Matching and retrieval of distorted and occluded shapes using dynamic programming," *IEEE Transactions on Pattern Analysis and Machine Intelligence* **24**, pp. 1501–1516, November 2002.
10. K. Mori, M. Ohira, M. Obata, K. Wada, and K. Toraichi, "A partial shape matching using wedge wave feature extraction," in *1997 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing – '10 Years PACRIM 1987-1997 - Networking the Pacific Rim'*, **2**, pp. 835–838, August 1997.