Extraction of the Euclidean skeleton based on a connectivity criterion

Wai-Pak Choi, Kin-Man Lam*, Wan-Chi Siu

Centre for Multimedia Signal Processing, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Received 5 October 2001; accepted 24 April 2002

Abstract

The skeleton is essential for general shape representation. The commonly required properties of a skeletonization algorithm are that the extracted skeleton should be accurate; robust to noise, position and rotation; able to reconstruct the original object; and able to produce a connected skeleton in order to preserve its topological and hierarchical properties. However, the use of a discrete image presents a lot of problems that may influence the extraction of the skeleton. Moreover, most of the methods are memory-intensive and computationally intensive, and require a complex data structure.

In this paper, we propose a fast, efficient and accurate skeletonization method for the extraction of a well-connected Euclidean skeleton based on a signed sequential Euclidean distance map. A connectivity criterion is proposed, which can be used to determine whether a given pixel is a skeleton point independently. The criterion is based on a set of point pairs along the object boundary, which are the nearest contour points to the pixel under consideration and its 8 neighbors. Our proposed method generates a connected Euclidean skeleton with a single pixel width without requiring a linking algorithm or iteration process. Experiments show that the runtime of our algorithm is faster than the distance transformation and is linearly proportional to the number of pixels of an image.

© 2002 Pattern Recognition Society. Published by Elsevier Science Ltd. All rights reserved.

Keywords: Skeletonization; Maximal disk; Medial axis transform; Distance transform

1. Introduction

The skeleton is essential for general shape representation. It is a useful means of shape description [1] in different areas, such as content-based image retrieval systems, character recognition systems, circuit board inspection systems, as well as biomedical imagery for shape analysis. The extracted skeleton can be used as a feature to represent the original shape as it has a more compact representation. In real-time image processing, a fast skeletonization algorithm is necessary.

Due to the importance of skeletonization, many approaches for it have been proposed throughout the past decades. Most of the skeletonization algorithms can be simply classified into two essential types. The first type is referred to as thinning algorithms, such as shape thinning [2–5] and the wave front/grassfire transform [6,7]. These algorithms iteratively remove border points, or move to the inner parts of an object in determining an object’s skeleton. However, the iterative process is a time-consuming operation and requires some terminating criteria. In addition, the uniqueness of the extracted skeleton may be dependent on the initial conditions provided. The second type of algorithm is based on the medial-axis transform, as introduced by Blum [1]. Examples include the line skeleton [8–10], Voronoi skeleton [11,12], morphological transform
Concerns for the skeletonization algorithms. Analytically, the connectivity of the skeleton can be proven by using the domain decomposition lemma [23]. In this lemma, a planar shape is continuously broken up into simpler pieces that are represented by the maximal disks. The centers of the disks are connected, and so is the skeleton. In the discrete case, it is assumed that the planar shape can be represented by polygons. With the use of the Voronoi diagram [11,12], a continuous skeleton can also be obtained analytically by the relationship between the skeleton and the Voronoi diagram. In Ref. [10], it is shown that each Voronoi diagram is path-connected and the skeleton is a sub-graph of the Voronoi diagram, so the connectivity of the skeleton is preserved. Consequently, both the continuity and the path-connectedness of a skeleton in discrete and continuous representations have been proven theoretically. However, there is no connectivity criterion for the extraction of the skeleton for efficient implementation.

An abundant amount of work on skeletonization and its application has been conducted, in which a profound theoretical background of the skeleton from different aspects has been provided. The properties of the skeleton, including its thickness, connectivity and reconstructability, have been investigated. In this paper, we propose a new skeletonization algorithm, which is fast, efficient and accurate, to extract a well-connected Euclidean skeleton based on a signed sequential Euclidean distance map. By using the connectivity criterion proposed in this paper, a skeleton point can be determined efficiently and independently by considering a set of points along the object’s boundary, which are the nearest contour points to the pixel under consideration and its 8 neighbors.

This paper is organized as follows. In Section 2, skeletonization based on the maximal disk is introduced and the definition of the medial axis transform is provided. Section 3 deals with the effect of discrete problems on the extraction of the skeleton. The concept of the width of a skeleton is established. The connectivity criterion for extracting a skeleton using the Euclidean metric is then proposed. Then, the algorithm is used to resolve different types of boundary segments. Section 4 illustrates and summarizes the implementation of the skeletonization algorithm. Finally, the experimental results and the conclusion are given in Sections 5 and 6, respectively.

2. Skeleton based on the maximal disk

Suppose that the contour \( C \) of an object in an image is represented by a continuous closed curve. Inside the contour \( C \), the planar shape \( F \) represents the content of the object. The corresponding skeleton \( S \) can be determined, as shown in Fig. 1. According to Blum’s definition [1], the skeleton \( S \) of a planar shape is defined as the locus of the centers of the maximal disks contained inside the planar shape \( F \). The
medial axis transform can then be defined as follows:

**Definition 1.** The medial axis transform is the set of ordered pairs of the centers and radii of maximal disks in the planar shape $F$. That is,

$$\text{SK}(F) = \{(p, r) \in F | B(p, r) \in \text{MaxDisk}(F)\},$$  \hspace{1cm} (1)

where MaxDisk($F$) is the set of all maximal disks in the planar shape $F$ and $B(p, r)$ is a disk with radius $r$ centered at the point $p$.

It can be observed that almost all skeleton points are associated with at least two boundary points whose respective distances to the skeleton point are the shortest except the end points of the skeleton. These boundary points divide the contour into different separate segments. In Fig. 1, with a maximal disk centered at $p$, the object’s contour and the maximal disk touch each other at the points $q_1$ and $q_2$. These two points divide the contour $C$ into two segments $A$ and $B$. If there exists at least one point along segment $A$ and along segment $B$ outside the maximal disk with a distance larger than a certain distance, which is called residual distance [24], the point $p$ will be declared to be a skeleton point. The residual distance can be used to form a pruned skeleton. The magnitude of the residual distance influences the accuracy of the skeleton for the original object.

### 3. The criterion for a skeleton point

#### 3.1. The width of skeleton

An ideal skeleton is connected and has zero width. A continuous boundary will produce a path-connected skeleton [23]. However, in real applications, the contour points and the skeleton points must be located at the pixel grids; this induces a lot of discrete problems. The skeleton may not pass through the pixel exactly. Hence, in practice, the skeleton has a non-zero width and all the pixels passed through by the ideal skeleton will be considered to be skeleton pixels. Consider a skeleton point $p$, the corresponding maximal disk touches the boundary at points $q_1$ and $q_2$, as shown in Fig. 2. Points $q_1$ and $q_2$ are the two nearest contour points with respect to point $p$. The distance between points $q_1$ and $q_2$ is denoted as $D$. Suppose that the true skeleton point $p$ lies midway between the two adjacent points $p_1$ and $p_2$. The width of the skeleton can then be represented by a line segment $p_1p_2$, which is parallel to the line $q_1q_2$ and perpendicular to the direction of the skeleton. Due to the width of the skeleton, two values, $r_1$ and $r_2$, which are the distances of $|p_1q_1|$ or $|p_2q_2|$, and $|p_1q_2|$ or $|p_2q_1|$, can be obtained with the condition that $r_2 > r_1$. By using the Cosine Law and $\angle q_1qp_1 = \angle q_2qp_2$, we have:

$$\frac{D^2 + r_2^2 - r_1^2}{2Dr_2} = \frac{w^2 + r_2^2 - r_1^2}{2wr_2} \Rightarrow w = \frac{r_2^2 - r_1^2}{D} = \frac{(r_2 - r_1)(r_2 + r_1)}{D}. \hspace{1cm} (2)$$

According to the above equation, the width of a skeleton is therefore proportional to the difference between the two local shortest distances and the radius of the maximal disk, and is inversely proportional to the value $D$, where $D$ is the distance between the two nearest contour points $q_1$ and $q_2$. Consequently, a skeleton of non-zero even width can be obtained if the following criterion is satisfied:

$$w = \frac{r_2^2 - r_1^2}{D} \leq \delta, \hspace{1cm} (3)$$

where $\delta$ is defined as a threshold to determine the maximum width of a skeleton and $w$ represents the corresponding width of the skeleton at a particular point.

For the point $p_1$, the first shortest distance $r_1$ is $|p_1q_1|$ while the second shortest distance $r_2$ is $|p_1q_2|$. Similarly, for the point $p_2$, the first shortest distance $r_1$ is $|p_2q_1|$ while the second shortest distance $r_2$ is $|p_2q_2|$. For the point lying midway between the points $p_1$ and $p_2$, the two...
shortest distances are equal, so the value of \( w \) is equal to zero, which is the exact position of the skeleton point. Any point \( p \) along the line \( \overline{p_1p_2} \) is also a skeleton point. Therefore, the criterion, as shown in Eq. (3), can be used to determine whether or not a point is a skeleton point with a given \( \delta \).

3.2. Connectivity of a skeleton on the square grid

The type of grid, such as square, hexagonal, etc., used for pixel position has different effect on the minimum width of the skeletons of an object under different orientations. Considering the square grid, the minimum width of a skeleton depends on its direction that is perpendicular to the line \( \overline{q_1q_2} \). Fig. 3 illustrates the effect of different orientations of a skeleton on the corresponding minimum width.

Suppose that the coordinates of the two nearest contour points \( q_1 \) and \( q_2 \) are \((x_1, y_1)\) and \((x_2, y_2)\), respectively. Since the direction of the line segment \( \overline{q_1q_2} \) is perpendicular to the direction of the skeleton, the minimum width \( \delta \) of the skeleton can be determined by the deviation of the line segment \( \overline{q_1q_2} \). If the horizontal deviation \( x \) is greater than the vertical deviation \( y \) of the line segment \( \overline{q_1q_2} \), as shown in Fig. 3(a), the minimum width \( \delta \) of the skeleton can be obtained as \( x = \overline{D} \) by considering the two similar triangles, \( \triangle q_1q_2q_3 \) and \( \triangle p_3p_2p_1 \). Similarly, if the horizontal deviation \( x \) is less than the vertical deviation \( y \) of the line segment \( \overline{q_1q_2} \), as shown in Fig. 3(b), the minimum width \( \delta \) of the skeleton can be obtained as \( y = \overline{D} \) by considering the two similar triangles, \( \triangle q_1q_2q_3 \) and \( \triangle p_1p_3p_2 \). The minimum width \( \delta \) of the skeleton can therefore be set as follows:

\[
\delta = \frac{\max(x, y)}{D},
\]

where \( x = \text{abs}(x_2 - x_1) \) and \( y = \text{abs}(y_2 - y_1) \), and the value \( D \) is the distance between the two nearest contour points \( q_1 \) and \( q_2 \).

A skeleton of non-zero width with threshold \( \delta \) is illustrated in Fig. 4. The thick solid line represents the ideal skeleton. All these pixels passed over by this ideal skeleton are considered to be a skeleton point. Therefore, the connectivity criterion for the square grid can be obtained based on Eqs. (3) and (4) as follows:

\[
r^2 - r_1^2 \leq \frac{\max(x, y)}{D} \quad \text{and} \quad D^2 \geq \rho,
\]

where \( x = \text{abs}(x_2 - x_1) \) and \( y = \text{abs}(y_2 - y_1) \), and \( \rho \) is a non-zero threshold used to determine the minimum distance between the two nearest contour points.

According to the connectivity criterion, we can observe that only the maximum of \( x \) and \( y \), which are the horizontal and vertical deviations of the line segment \( \overline{q_1q_2} \), and the two lengths of the line segments, \( \overline{pq_1} \) and \( \overline{pq_2} \), are considered in the determination of a skeleton point. This criterion can be extended to the contour surface of a 3D object when considering the minimum width of the connected skeleton of the 3D object. Based on the connectivity criterion, the minimum widths for a connected skeleton in 2D case are 0.707 and 1.000 units, respectively, in the diagonal and vertical/horizontal directions. The true skeleton line, which is represented by the dark line in Fig. 4, may not pass through the skeleton pixel exactly. The skeleton with
non-zero width is represented by the gray regions, which include all the connected skeleton pixels satisfying the connectivity criterion.

3.3. Types of boundary segments

Since the skeleton points are determined based on the connectivity criterion, simple contour segments that are either in a horizontal/vertical or a diagonal direction will cause some points to be mistaken for skeleton points. These points can be removed by simply determining the corresponding segment type. For example, Fig. 5 illustrates the values of the square distances $D^2$ between the two nearest contour points. The pixel under consideration is represented by a shaded square, while the corresponding two nearest contour points are represented by white squares. With Eq. (5), only those pixels having the corresponding distance $D^2$ greater than the threshold $\rho$ will be considered as skeleton points. Two adjacent 8-connected contour points have $D^2 = 1$ and 2 for vertical/horizontal and diagonal boundary segments, respectively, as shown in Fig. 5(a) and (b). In order to exclude the pixels in these two cases as skeleton points, we set $\rho^2$ to be 4. Consequently, the pixels under consideration, as shown in Fig. 5(c) and (d), will be considered as skeleton points. Actually, if a larger value is set for $\rho^2$, the number of redundant branches in the skeleton will be reduced.

4. The skeletonization algorithm

To determine whether a pixel point is a skeleton point, the corresponding nearest contour point for each of the 8 neighboring points will be determined, and the connectivity criterion will then be applied to this set of 8 contour point pairs. The relative positions of the nearest contour points for each pixel can be obtained by using the signed sequential Euclidean distance (8SSED) map. The nearest contour points for each of the 8 neighboring points of the point under consideration can be obtained by subtracting the relative position of its nearest contour point from the relative position of its neighborhoods. The nearest contour points of the pixel under consideration and one of its 8 neighbors then form a point pair. If any one of the point pairs satisfies the connectivity criterion, the pixel can be declared a skeleton point. Otherwise, if all the 8 point pairs fail to fulfill the connectivity criterion, the pixel is not a skeleton point. In summary, the procedure of our proposed algorithm is described as follows:

Find the nearest contour points of its 8 neighbors $P_i$ $Q_i = DM(P) + (x_i, y_i)$ where $(x_i, y_i)$ is the relative position of the neighborhood $i$ with respect to the pixel $P$ and $i = 1, 2, \ldots, 8$ is the index of the neighborhoods.

The eight point pairs are formed by the nearest contour points of both the pixel $P$ and its 8-neighbors, which are denoted as $(Q, Q_i)$ where $i = 1, 2, \ldots, 8$.

Apply the connectivity criterion: $D^2 = |Q - Q_i|^2 \geq \rho$ and $|Q|^2 - |Q_i|^2 \leq \max(X(Q_i - Q), Y(Q_i - Q))$

where $X(p)$ and $Y(p)$ represent the $x$ and $y$ coordinates of the point.

If one of the point pairs, $(Q, Q_i)$, satisfies the connectivity criterion, then the pixel $P$ is a skeleton point.

until the last pixel of the image checked

Fig. 6 illustrates an example of skeletonization based on the above procedure. The white square represents the boundary points and the gray squares represent the pixels inside the boundary. The pixel under consideration is $P$, and its 8 neighbors are represented as $P_1, P_2, P_3, P_4, P_5, P_6, P_7$ and $P_8$. The relative positions of the nearest contour point for each pixel are obtained by using the signed sequential Euclidean distance transformation. The nearest contour point to the pixel $P$ is located at the position $A$, which is $(0, 2)$ relative to its position. Similarly, the nearest contour points of its 8 neighbors $(P_2, P_3, P_5, P_8)$ and $(P_1, P_4, P_6, P_7)$ are at positions $A(0, 2)$ and $B(-2, 1)$ relative to the pixel $P$, respectively. For example, the nearest contour point of $P_1$ is calculated as $(-1, 0) + (-1, 1) = (-2, 1)$, which is its position relative to the pixel $P$. Since the nearest contour points of some of the 8 neighbors are the same as the nearest contour point of the pixel $P$, the exact number of point pairs considered in this case is one, which is formed by the points $A(0, 2)$ and $B(-2, 1)$. Based on this point pair, the square distance $D^2$ between these two nearest contour points is $|0, 2 - (-2, 1)|^2 = 5$ which is greater than the threshold $\rho = 4$. The width of the skeleton, $w$, is $[(-2 + 1) - (0 + 2)]/\max(2, 1) = 0.5$, which is less than one, and thus satisfies the connectivity criterion. Consequently, the pixel $P$ is declared an Euclidean skeleton point. As the square root operation is not required in the procedure, this algorithm is very efficient.

5. Experimental results

In the experiment, the shapes in an image can be extracted by using a contour extraction method called the adaptive snake method [25] or any edge follower method. Based
on the extracted contours, the skeletons of the shapes are extracted using our proposed algorithm. The skeletonization performance and the complexity of our proposed algorithm are evaluated in this section. The effect of the threshold values $\rho$ on the extraction of a skeleton will be illustrated. Then, the complexity of our proposed algorithm is compared to some maximal disk extraction algorithms. The experiments were conducted on a Pentium II 400 MHz PC. The signed sequential Euclidean distance map (8SED) [22] was used in all the methods to be compared.

5.1. The effect of the threshold $\rho$

The effect of different threshold values $\rho$ on the skeleton of an object is illustrated in Fig. 7. The whole skeleton extracted by using our proposed algorithm is shown in Fig. 7(a), which uses the threshold value $\rho = 4$. When the value of the threshold $\rho$ increases, a smaller number of skeleton points will be extracted and as a result there will be fewer branches in the skeleton. The effect of increasing the threshold $\rho$ is similar to that of pruning. However, this pruning procedure may cause the extracted skeleton to disconnect from some spurious points, as shown in Fig. 7(b), because there is no guarantee of extracting a connected skeleton for a larger value of $\rho$. Since many pruning methods [11,12,26] have been proposed, we can apply one of them after we have applied our proposed algorithm to extract the Euclidean skeleton. Alternatively, we can use a larger threshold $\rho$ as a simple pruning method to extract the pruned skeleton, as shown in Fig. 7(c).

5.2. The computational requirements of the algorithms

In this section, we will investigate the computational complexity of our proposed method. As mentioned previously, there are many approaches for extracting a skeleton, and it is impossible to compare our proposed method with each of the existing methods. In this paper, we will compare our algorithm to the following existing methods, namely, method 1, a neighborhood algorithm followed by an exhaustive algorithm [19]; method 2, a modification of method 1 with the use of an exhaustive algorithm followed by a bounding box-based algorithm [19]; and method 3, a method based on a criterion with a residual distance [24].

Both methods 1 and 2 use the neighborhood algorithm to eliminate most of the points in the planar shape by means of the inclusion test procedure [19]. In order to determine the true maximal disks, the exhaustive algorithm is used to screen out the rest of the non-CMDs. The testing procedure is very computationally intensive because all the possible sets of points are used in the inclusion test procedure. By applying the bounding box-based algorithm before the exhaustive algorithm, the computational time for method 2 can be reduced and a smaller number of false CMDs will be generated. Both methods 1 and 2 can be used to reconstruct the original contour exactly, and so be used as a means for compression, but they require a linking algorithm [19] to obtain a connected skeleton. Method 3 can extract a pruned connected skeleton directly without using a linking algorithm.

As shown in Table 1, the runtimes for methods 1, 2 and 3 are longer than that for the proposed method. Theoretically, the complexity of an exhaustive algorithm is in the order of $O_1(n^2)$, where $n$ is the number of points in the planar shape. With the neighborhood method, the complexity in terms of testing and finding the maximal disks in the neighborhood of each point in the planar shape is in the order of $O_2(kn)$, where $k$ is the size of the neighborhood. The computation time is reduced significantly compared to the exhaustive algorithm due to the use of the bounding box-based algorithm to eliminate the irrelevant disks. For method 3, the
Fig. 7. The skeletons using different thresholds $\rho$ with an image of size $320 \times 240$.

Table 1
A comparison of different methods with different images

<table>
<thead>
<tr>
<th>Input images</th>
<th>8SSED Method 1: Neighborhood + exhaustive method</th>
<th>Method 2: Neighborhood + bounding box-based + exhaustive method</th>
<th>Method 3: Criteria of a skeleton</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Method 1 (s)</td>
<td>Method 2 (s)</td>
<td>Method 3 (s)</td>
<td>Method 3 (s)</td>
</tr>
<tr>
<td></td>
<td>Neighborhood + exhaustive method</td>
<td>Neighborhood + bounding box-based + exhaustive method</td>
<td>Criteria of a skeleton</td>
<td>Proposed method</td>
</tr>
<tr>
<td></td>
<td>(s)</td>
<td>(s)</td>
<td>(s)</td>
<td>(s)</td>
</tr>
<tr>
<td>No. 1 320 × 240</td>
<td>0.0700</td>
<td>5.6680</td>
<td>5.5380</td>
<td>4.3770</td>
</tr>
<tr>
<td>640 × 480</td>
<td>0.2810</td>
<td>65.9650</td>
<td>58.3340</td>
<td>34.2800</td>
</tr>
<tr>
<td>1280 × 960</td>
<td>1.1520</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No. 2 320 × 240</td>
<td>0.0700</td>
<td>5.1570</td>
<td>5.0170</td>
<td>3.2450</td>
</tr>
<tr>
<td>640 × 480</td>
<td>0.2810</td>
<td>61.1280</td>
<td>55.3400</td>
<td>28.6110</td>
</tr>
<tr>
<td>1280 × 960</td>
<td>1.1520</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No. 3 320 × 240</td>
<td>0.0700</td>
<td>5.0570</td>
<td>5.5680</td>
<td>3.7650</td>
</tr>
<tr>
<td>640 × 480</td>
<td>0.2810</td>
<td>28.6110</td>
<td>28.6110</td>
<td>29.3020</td>
</tr>
<tr>
<td>1280 × 960</td>
<td>1.1520</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Fig. 8. The skeletons based on our proposed algorithm with an image of size $640 \times 480$.

complexity of the algorithm is in the order of $O(n^3)$, where $m$ is the total number of contour points. This method computes the distances to the contour instead of checking the inclusion and overlapping of the maximal disks. For the proposed method, its computational complexity is in the order of $O(8n)$ only, because it only considers the pixel under consideration and its 8 neighbors by means of the connectivity criterion. In addition, the square root operation is not needed in this algorithm. In Table 1, we can observe that the runtimes required by the three methods increase tremendously when the image size increases. For our proposed method, the runtime is linearly proportional to the number of pixels in the planar shape. Fig. 8 illustrates some of the extracted skeletons based on our algorithm.

6. Conclusions

With the use of the connectivity criterion proposed in this paper, an accurate, simple and efficient algorithm for the extraction of a well-connected Euclidean skeleton is devised with the use of the signed sequential Euclidean distance map. The nearest contour points of the pixel under consideration and its 8 neighbors are generated to form a set of 8 point pairs, which are then used to determine whether the pixel is a skeleton point. This method can generate a connected Euclidean skeleton without requiring a linking algorithm or any iteration. The complexity of this algorithm is linearly proportional to the number of the pixels in an image. The computational complexity is $O(8n)$ where $n$
is the total number of pixels in the image. No square root operation is needed in the algorithm.

References


About the Author—WAI-PAK CHOI received his B.Eng. in Electronic Engineering from the City University of Hong Kong in 1992. He is now a Ph.D. student in the Department of Electronic and Information Engineering, The Hong Kong Polytechnic University. His research interests are in the areas of image processing and pattern recognition.

About the Author—KIN-MAN LAM received his Associateship in Electronic Engineering from The Hong Kong Polytechnic University (formerly called Hong Kong Polytechnic) in 1986. He won the S.L. Poa Scholarship for overseas studies and was awarded an M.Sc. degree in communication engineering from the Department of Electrical Engineering, Imperial College of Science, Technology and Medicine, England, in 1987. In 1993, he undertook a Ph.D. program in the Department of Electrical Engineering at the University of Sydney, Australia, and won an Australia Postgraduate Award for his studies. He completed his Ph.D. studies in August 1996, and was awarded the IBM Australia Research Student Project Prize.

From 1990 to 1993, Dr. Lam was a lecturer at the Department of Electronic Engineering of the Hong Kong Polytechnic University teaching various subjects on computer architecture and parallel processing. In October 1996, he was appointed as an Assistant Prof. at The Hong Kong Polytechnic University, and has been an Associate Professor since October 1996. Dr. Lam was a member of the Technical Program Committee of the IEEE Symposium on Circuits and Systems (ISCAS’97). He was also the Secretary of the Hong Kong Special Session for the China Fourteenth National Conference on Circuits and Systems in April 1998, and the Secretary of the 2001 International Symposium on Intelligent Multimedia, Video and Speech Processing in May 2001. He was also a Program Committee Member of the 2002 Conference on Visual Communications and Image Processing.
Currently, Dr. Lam is the Secretary of the IEEE Hong Kong Chapter of Signal Processing, the Secretary of the 2003 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2003), and the Principal Member of Technical Programs of the 2002 Seventh International Conference on Control, Automation, Robotics and Vision (ICARCV 2002). In addition, Dr. Lam is a Guest Editor for the Special Issue on Biometric Signal Processing, EURASIP Journal on Applied Signal Processing. His current research interests include video processing, computer vision and architecture, digital TV and pattern recognition.

About the Author—WAN-CHI SIU received the Associateship from The Hong Kong Polytechnic University (formerly called the Hong Kong Polytechnic), the MPhil degree from The Chinese University of Hong Kong and the Ph.D. degree from Imperial College of Science, Technology & Medicine, London, in 1975, 1977 and 1984, respectively. He was with The Chinese University of Hong Kong between 1975 and 1980. He then joined The Hong Kong Polytechnic University as a Lecturer in 1980 and has become Chair Prof. since 1992. He took up administrative duties as Associate Dean of Engineering Faculty between 1992 and 1994 and Head of Department of Electronic and Information Engineering between 1994 and 2000. Prof. Siu has been Director of Centre for Multimedia Signal Processing and Dean of Engineering Faculty of the same university since September 1998 and September 2000, respectively. He has published over 200 research papers, and his research interests include digital signal processing, fast computational algorithms, transforms, image and video coding, and computational aspects of pattern recognition and neural networks.

Prof. Siu is a Member of the Editorial Board of the Journal of VLSI Signal Processing Systems for Signal, Image and Video Technology and the EURASIP Journal on Applied Signal Processing. He was a Guest Editor of a Special Issue of the IEEE Transactions on Circuits and Systems, Pt.II published in May 1998, and was also an Associate Editor of the IEEE Transactions on Circuits and Systems, Pt.II between 1995 and 1997. Prof. Siu was the general chair or the technical program chair of a number of international conferences. In particular, he was a Co-Chair of the Technical Program Committee of the IEEE International Symposium on Circuits and Systems (ISCAS’97) and the General Chair of the 2001 International Symposium on Intelligent Multimedia, Video & Speech Processing (ISIMP’2001) which were held in Hong Kong in June 1997 and May 2001, respectively. Prof. Siu is now the General Chair of the 2003 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP’2003) which will be held in Hong Kong. Between 1991 and 1995, Prof. Siu was a member of the Physical Sciences and Engineering Panel of the Research Grants Council (RGC), Hong Kong Government, and in 1994 he chaired the first Engineering and Information Technology Panel to assess the research quality of 19 Cost Centers (departments) from all universities in Hong Kong.Prof. Siu is a Chartered Engineer, a Fellow of the IEE and the HKIE, and a Senior Member of the IEEE, and has also been listed in Marquis Who’s Who in the World, Marquis Who’s Who in Science and Engineering and other citation biographies.