Closed boundary extraction of cancer cells using fuzzy edge linking technique

Wing-Kuen Ling and Peter, Kwong-Shun Tam
Department of Electronic and Information Engineering,
The Hong Kong Polytechnic University,
Hung Hom, Kowloon, Hong Kong, China.
Tel: (852) 2766 4094, Fax: (852) 2362 8439
Email: bingo@encserver.eie.polyu.edu.hk

ABSTRACT

Edge linking is an important task in a boundary extraction problem. In this paper, a fuzzy approach is proposed. The proposed system consists of a fuzzy edge detection module and a fuzzy edge linking module, respectively. The fuzzy edge detector gives a fuzzy membership matrix and an initial edge map. Once the initial edge map is obtained, the pairing of the start and end points of the edges as well as the linking of appropriate segments of edges in the map can be found using the fuzzy edge linking module, as follows: First, for any start point, the corresponding end point is found by searching for the shortest distance between the points. Second, for any start point as a reference point, we search for the greatest fuzzy membership value among its neighbors, and connect the reference point to that neighbor. Then with that neighbor as the new reference point, this step of searching is repeated until the end point is reached. After applying the above technique to all the pairs of start and end points, all the open boundaries will be connected. A simulation evaluation of the proposed technique was carried out on an image “Cancer”. The simulation result shows an improvement on the outlines of the cancer cells. The proposed algorithm is simple and low cost, and can be implemented easily in some real-time applications.

Keywords: Edge linking, boundary extraction, fuzzy edge detection module, fuzzy edge linking module, fuzzy membership matrix, edge map

1. INTRODUCTION

Many biomedical objects, such as cancer cells, do not contain clearly defined boundaries. If the biomedical images contain noises and textures, then the edge maps produced by an edge detector will be discontinuous and contain isolated points and unwanted line segments. In order to work on this problem, edges are linked together [1-3]. Hence, edge linking usually is the first step in a boundary extraction problem and plays an important role in medical diagnosis. For example, in the processing of cancer cell images, once the edges of the cancer cells are linked together, the shapes of the cancer cells can be seen more clearly. As the shapes of the cancer cells provide useful information for the medical professionals to decide the types of the cancer cells, thus, the technique helps to reduce the time and improves the accuracy for the diagnosis procedure.

Although some existing edge linking algorithms [1-3] can join discontinuous edges together, they have drawbacks. An algorithm for edge linking using a neural network approach is proposed in [1], in which the output of the converged neurons represent the linked edge segments in an image. Although this method is effective, it takes a long time for the neural network to converge. Hence, this method cannot be used for some real-time applications and the computation cost is very high. In order to solve the computation cost and real-time problem, a simple edge detection algorithm is proposed in [2]. However, the proposed algorithm cannot guarantee to produce a closed boundary. Also, the linked edge quality is sensitive to the choice of the threshold values employed in the algorithm. A statistical approach is proposed in [3]. In this approach, the probability density functions are estimated using a Gaussian model, and then a linked edge path is found by a recursive method. Although no threshold is required, the estimated probability is not accurate because the estimation is based on one somewhat simplistic Gaussian model only.

In this paper, a fuzzy approach is proposed. The paper is organized as follows: the proposed algorithm is described in section 2 and simulation results are shown in section 3, respectively. Section 4 presents the conclusion.

2. PROPOSED ALGORITHM

The proposed boundary detection system consists of a fuzzy edge detection module and a fuzzy edge linking module, as shown in figure 1.

2.1 Fuzzy edge detection module

Since the human vision system is more sensitive to edges than the background textures and the nature of a boundary itself is an edge, it is often worthwhile to employ a dedicated edge detection module. Our proposed fuzzy edge detector gives a fuzzy membership matrix $\boldsymbol{\mu}$ and an edge map $\mathbf{E}$, respectively. Let $\mathbf{X}$ be the matrix representing an image, $\mathbf{T_i}$ be the ith existing edge detector, and $\mathbf{Y_i}$ be the matrix representing the output of the ith edge detector, respectively. Then $\mathbf{Y_i}$ can be expressed as:

$$\mathbf{Y_i}=\mathbf{T_i}(\mathbf{X}), \tag{1}$$

and the elements of the fuzzy membership matrix are defined as:

$$\mu(x,y)=\max_{\forall i}\frac{Y_i(x,y)-\min\limits_{\forall(x,y)}Y_i(x,y)}{\max\limits_{\forall(x,y)}Y_i(x,y)-\min\limits_{\forall(x,y)}Y_i(x,y)}. \tag{2}$$

The fuzzy membership matrix gives the 'likelihood' of a pixel to be at an edge location.

The fuzzy membership value $\mu(x,y)$ has to be mapped to a crisp point $E(x,y)\in\{0,1\}$. The simplest way is to let the mapping operate as a discriminator with an appropriately selected threshold value.

2.2 Fuzzy edge linking module

The first step before processing is to decide whether any edge segment is part of a boundary of some cancer cell or not. If the edge segment is due to the presence of noise or background texture, we will delete it. Otherwise, we will join some neighbor edge segment together based on the fuzzy edge map provided by the fuzzy edge detection module.

2.2.1 Edge information unit

In order to delete inappropriate false edges or link different edge segments together, we need to know the coordinates of the start points and the end points, as well as the connectivity of the edges. The connectivity describes the orientation of how an edge connects from the start coordinates to the end coordinates. We employ the 8-connectivity scheme to describe the edge orientation.

2.2.2 Edge deleting unit

Due to the presence of the noise and the background texture, an edge detector will give a lot of isolated points and unwanted line segments as shown in figure 2. In order to prevent the connecting of those false edges together in the fuzzy edge linking unit, we need to delete those isolated points and unwanted line segments. The criteria for deleting the edges are based on the following expert knowledge:

[K1] The boundary of a cancer cell should be a closed trajectory.

[K2] The number of pixels at the boundaries of different cancer cells are approximately of the same order.

Since the boundary of a cancer cell should be a closed trajectory, the coordinates of the start point coincide with that of the end point for those closed-trajectory edges. Hence, we just keep those edges and process another one if we find the edges with the coordinates of the start point being the same as that of the end point.

For an open-trajectory edge, the coordinates of the start point are different from that of the end point. There are two types of open-trajectory edge, one is almost closed and for the other, the coordinates between the start point and the end point are far apart. Most of the former ones are at the boundaries of the cancer cells. However, the latter ones are due to the presence of the background texture.

For an open-trajectory edge which is almost closed, the arc length of the edge should be longer than, say, two times the distance between the start point and the end point of that edge. However, for an edge for which the coordinates between the start point and the end point are far apart, the arc length of the edge should approximately equal to the distance between the start point and the end point of that edge. Hence, we propose to delete those open-trajectory edges with the number of the pixels in the edge being smaller than two times the distance between the start point and the end point. This criterion is found to be effective in deleting those false edges due to the presence of the background texture.

The number of pixels at the boundaries of different cancer cells are approximately of the same order, and these numbers depend on the resolution of the image. For those edges due to the presence of noise, they are usually shorter in length and some are isolated points. Hence, we propose to delete those 'edges' with the number of pixels at the boundary less than one standard deviation below the mean. This criterion is also found to be effective in deleting those false edges due to the presence of noise.

2.2.3 Fuzzy edge linking unit

After deleting those isolated points and unwanted edges due to the presence of noise and background texture, we can join the neighbor edges together. The first step is to decide which edges are connected together. This is based on the separation among the edges as follows:

Let $D_{i,j}^{start\_start}$ be the distance between the start coordinates of the i^{th} edge to that of the j^{th} edge, $D_{i,j}^{start\_end}$ be the distance between the start coordinates of the i^{th} edge to the end coordinates of the j^{th} edge, $D_{i,j}^{end\_start}$ be the distance between the end coordinates of the i^{th} edge and the start coordinates of the j^{th} edge, and $D_{i,j}^{end\_end}$ be the distance between the end coordinates of the i^{th} edge and that of the j^{th} edge. That is:

$$D_{i,j}^{start\_start} = \sqrt{\left(x_i^{start} - x_j^{start}\right)^2 + \left(y_i^{start} - y_j^{start}\right)^2}\,, \tag{3}$$

$$D_{i,j}^{start\_end} = \sqrt{\left(x_i^{start} - x_j^{end}\right)^2 + \left(y_i^{start} - y_j^{end}\right)^2}\,, \tag{4}$$

$$D_{i,j}^{end\_start} = \sqrt{\left(x_i^{end} - x_j^{start}\right)^2 + \left(y_i^{end} - y_j^{start}\right)^2}\,, \tag{5}$$

and

$$D_{i,j}^{end\_end} = \sqrt{\left(x_i^{end} - x_j^{end}\right)^2 + \left(y_i^{end} - y_j^{end}\right)^2}\,. \tag{6}$$

We would like to join a start/end point of the i^{th} edge to a start/end point of the j^{th} edge if $D_{i,j}^{start/end\_start/end}$ is the minimum among the above four parameters.

If $i=j$, we would join the start point and the end point of the same edge together and we obtain a closed boundary. However, it is found that we may not be able to always connect the start and end points in this manner because the boundary of a cancer cell may be broken down into several segments and we need to join those segments together.

Once we have located the edges to be connected together, we will go into the edge linking procedure. The linking of the node P_i to another node P_j is based on the fuzzy membership map generated in the fuzzy edge detection unit. We examine the neighborhood pixels of the start node and select the pixel for which the fuzzy membership value is the maximum compared with its neighbor pixels. The selected pixel now becomes the new start node and the process is repeated until the end node is reached. This method will generate the mostly boundary from the node P_i to node P_j.

3. SIMUALTION RESULTS

The simulation results are demonstrated through the cancer images of different patients with size *512x512* as shown in figure 2 to figure 5. In comparison with the existing method of [2], it can be seen that the boundaries extracted by our proposed algorithm are more 'closed' and 'continuous', while the edges due to the presence of noise and background texture are reduced.

4. CONCLUSION

We have proposed a fuzzy approach to extract the closed-boundaries of cancer cells. It first detects the edge information of the image. Then, those false edges with isolated points and unwanted line segments will be deleted. Finally, appropriate edge segments are connected together by means of fuzzy approach. The proposed algorithm is simple and low cost, and can be implemented easily in some real-time applications. Also, the proposed algorithm guarantees to produce a closed boundary. Moreover, as the fuzzy edge detector captures the expert knowledge from various expert systems, the boundaries are more complete than those employing any one of the expert systems, while the effects due to noise and background texture are minimized.

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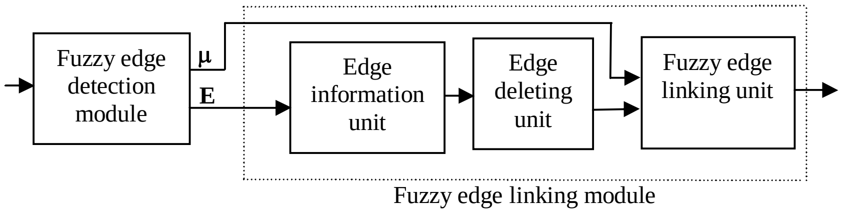

Fig. 1. System block diagram of boundary extraction

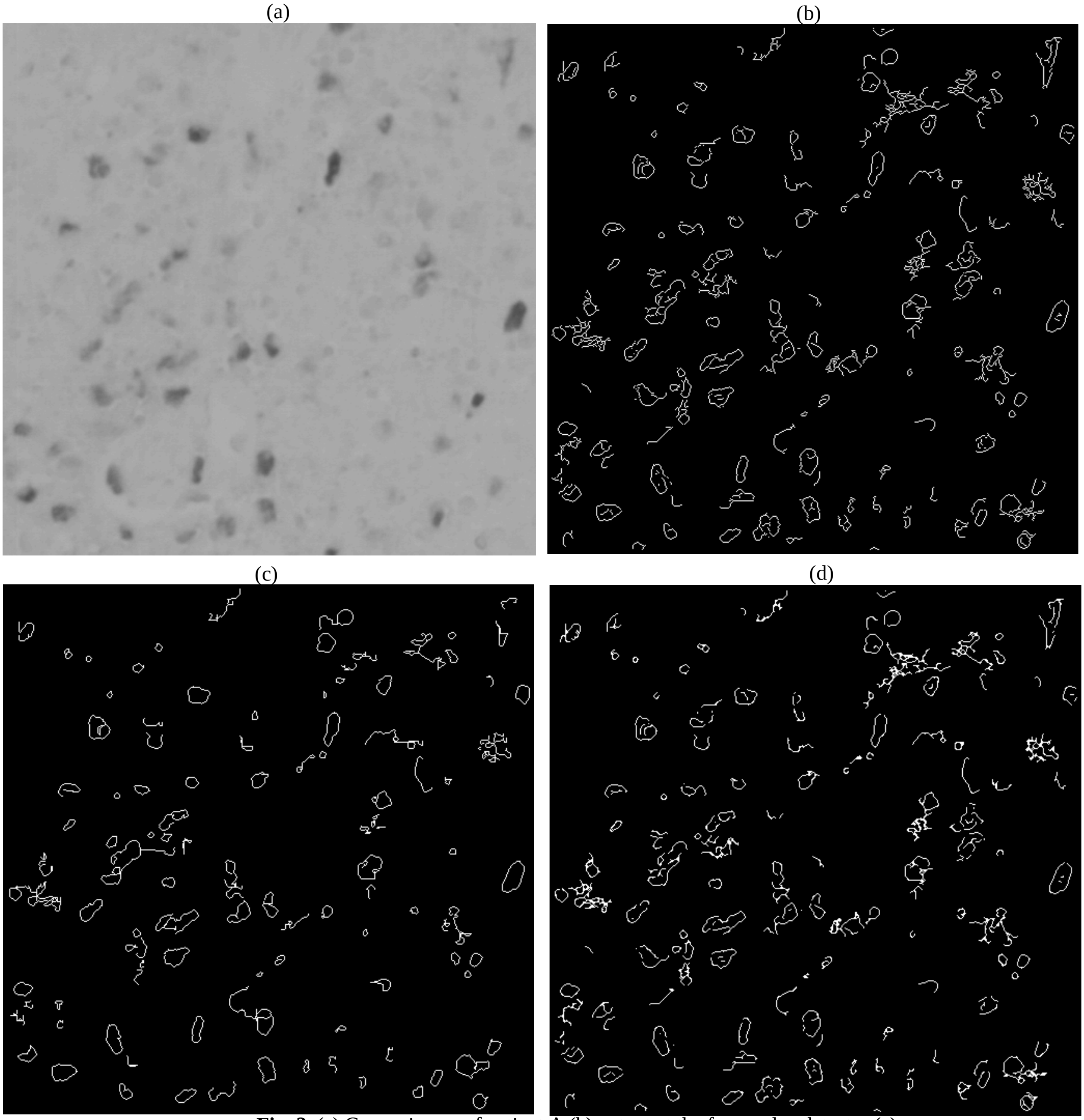

Fig. 2. (a) Cancer image of patient A (b) output at the fuzzy edge detector (c) output at the fuzzy edge linking module (d) output of edge linking module using [2]

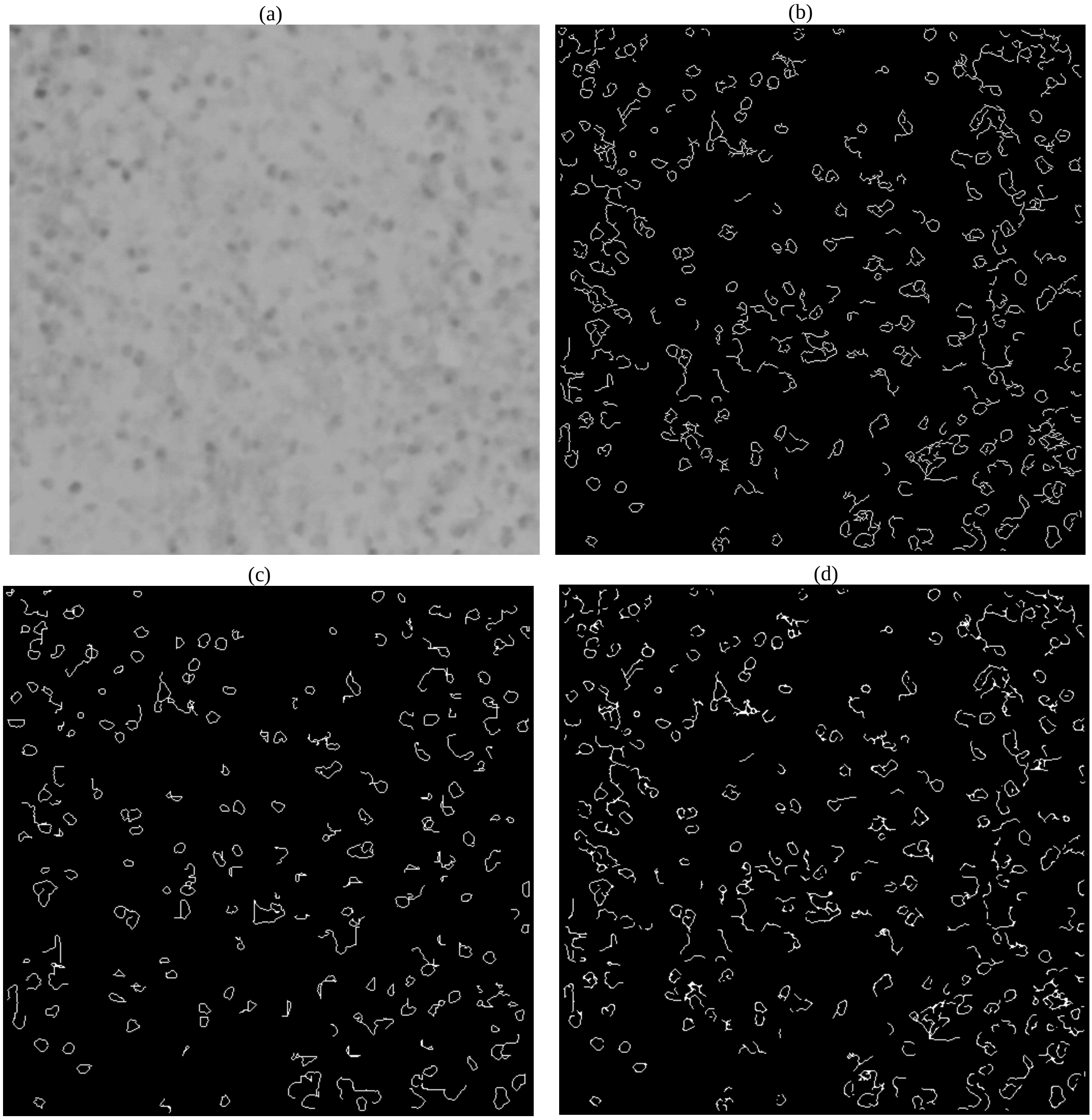

Fig. 3. (a) Cancer image of patient B (b) output at the fuzzy edge detector (c) output at the fuzzy edge linking module (d) output of edge linking module using [2]

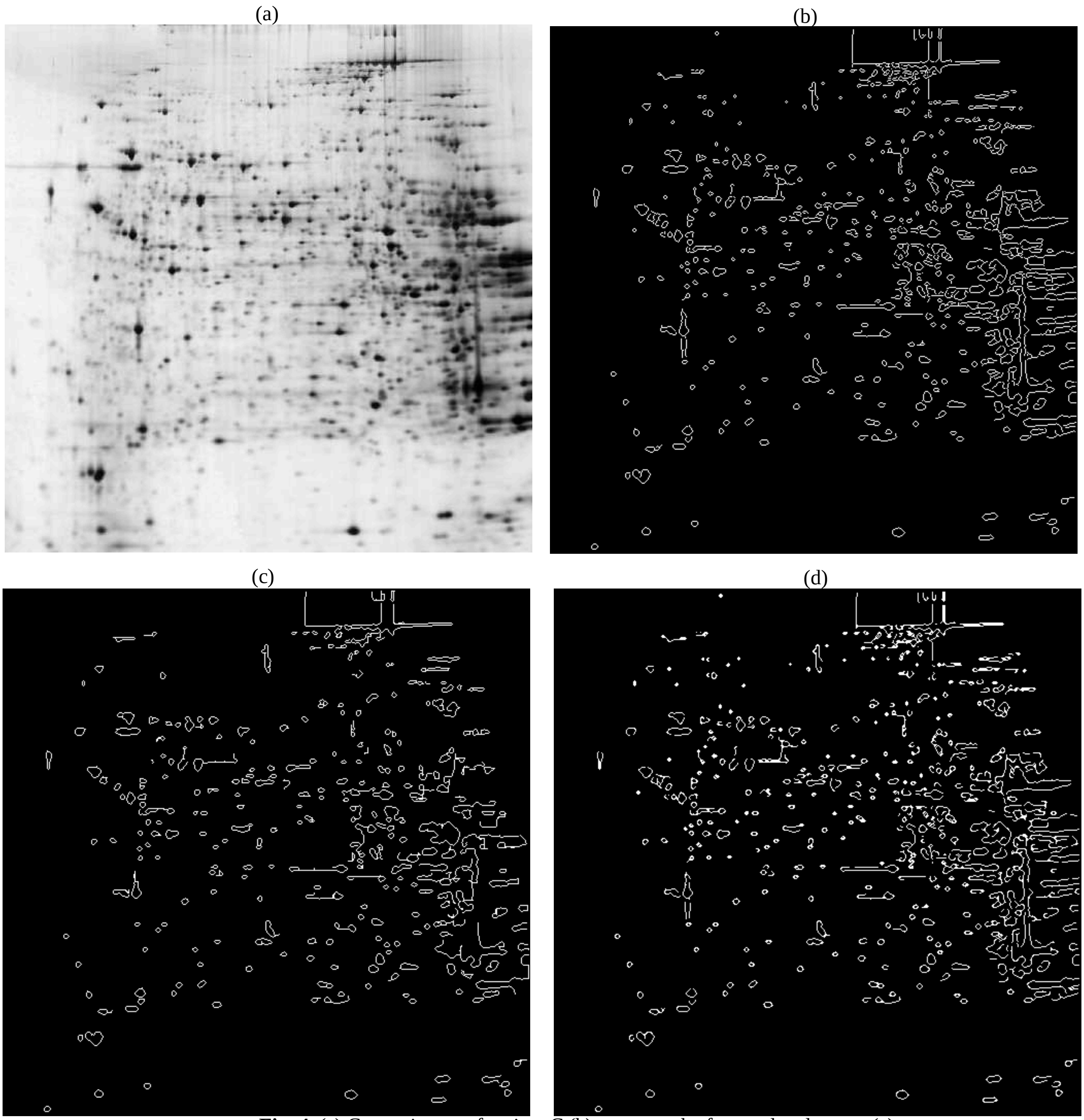

Fig. 4. (a) Cancer image of patient C (b) output at the fuzzy edge detector (c) output at the fuzzy edge linking module (d) output of edge linking module using [2]

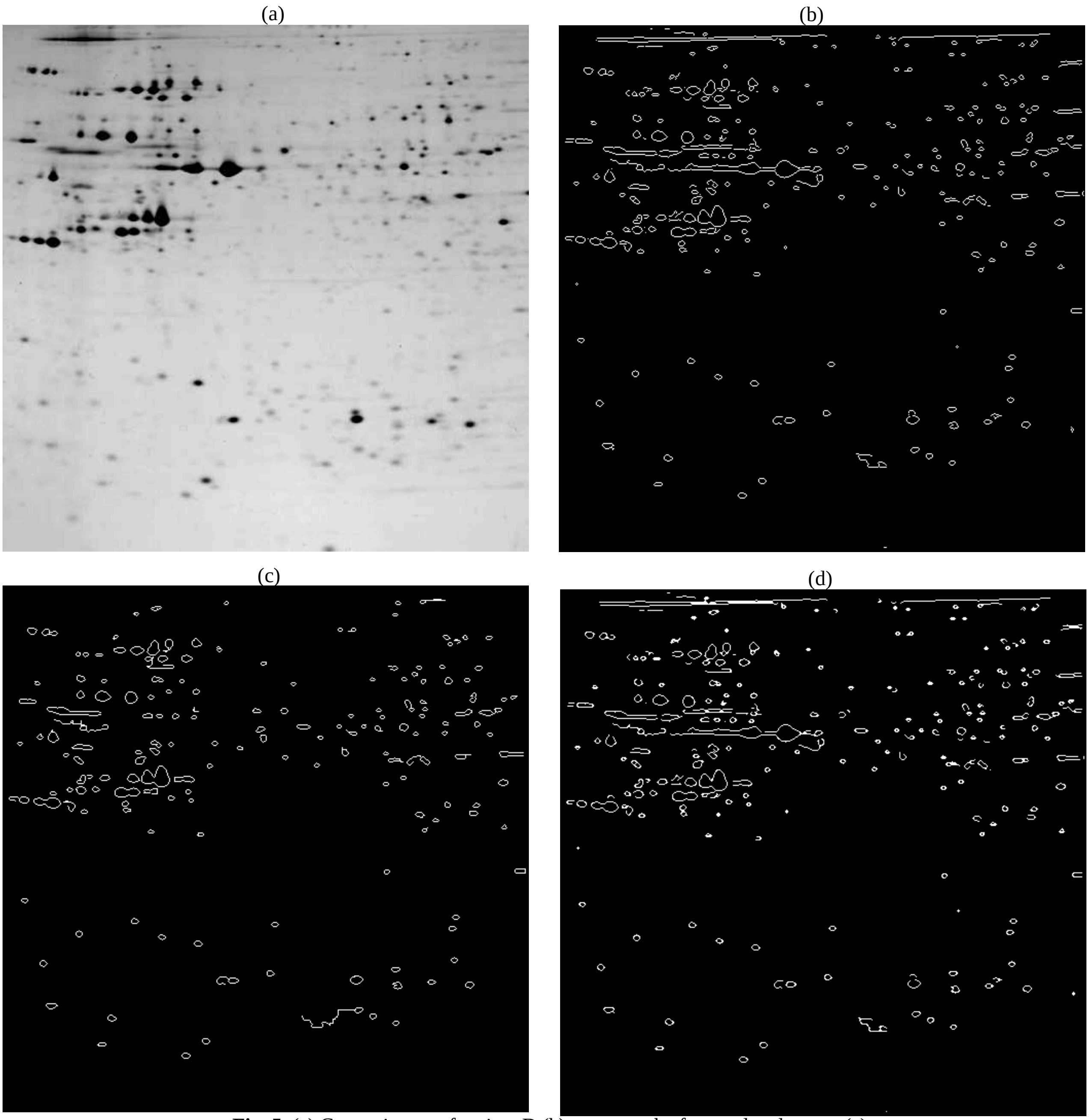

Fig. 5. (a) Cancer image of patient D (b) output at the fuzzy edge detector (c) output at the fuzzy edge linking module (d) output of edge linking module using [2]