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SEGMENTATION OF BREAST THERMOGRAM: IMPROVED BOUNDARY DETECTION WITH MODIFIED SNAKE ALGORITHM

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Background: Breast cancer is a common and dreadful disease in women. One in five cancers in Singaporean women is due to breast cancer. Breast health is every woman's right and responsibility. In average, every $100 spent on breast mammogram screening, an additional $33 was spent on evaluating possible false-positive results. Thermography, with its non-radiation, non-contact and low-cost basis has been demonstrated to be a valuable and safe early risk marker of breast pathology, and an excellent case management tool available today in the ongoing monitoring and treatment of breast disease. The surface temperature and the vascularization pattern of the breast could indicate breast diseases and early detection saves lives. To establish the surface isotherm pattern of the breast and the normal range of cyclic variations of temperature distribution can assist in identifying the abnormal infrared images of diseased breasts. Before these thermograms can be analyzed objectively via computer algorithm, they must be digitized and segmented. The authors present a method to segment thermograms and extract useful region from the background. Thermography could detect the presence of tumors much earlier and of much smaller size than mammography. This paper thus aims to develop an intelligent diagnostic system based on thermography for the detection of tumors in breast. **Methods:** We have examined about 50 normal, healthy female volunteers in Nanyang Technological University and 130 patients in Singapore General Hospital. We did the examinations for some of them continuously for two months. From these examinations, we obtained about 1000 thermograms for contact and 800 thermograms for non-contact approaches. Standard ambient conditions were observed for all examinations. The thermograms obtained were analyzed. The first step in processing these thermograms is image segmentation. Its aim is to discern the useful region from the background. In general, autonomous segmentation is one of the most difficult tasks in image

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processing. This step in the process determines the eventual success or failure of the analysis. In this work, two different techniques have been presented to extract the objects from the background. **Results:** After analyzing these thermograms and with reference to some relevant well-documented papers, we were able to classify the thermograms. The step is very useful in identifying the normal or suspected (abnormal) thermograms. A series of thermograms was studied with the help of the in-house developed computer software. On the basis of the anatomic and vascular symmetry, the surface temperature distributions of both left and right breasts were compared. The surface isotherm pattern of breasts can indicate the local metabolism and vascularity of the underlying tissues, and the change in local blood or glandular activities can be reflected in the surface temperature of breast. We evaluated the temperature distribution pattern and the menstrual cyclic variation of temperature with time. All these results can be used to detect breast cancer. **Conclusion:** Automatic identification of object and surface boundary of breast thermal images is a difficult and challenging task. Both the traditional snake and gradient vector flow snake failed to detect the boundary of these images successfully. In this work, a new method is proposed in conjunction with image pre-processing, image transition, image derivative, filtering and gradient vector flow snake. This novel method can easily detect the boundary of the breast thermal image with good agreement.

Keywords: Thermography; image segmentation; boundary detection; snake; active contour tracking.

1. Background

Breast cancer and other breast diseases are a major issue in women's health today. In the past, due to limitations in the interpretation of non-digitized thermal images, breast thermography has gone largely unnoticed and under-utilized as a method for the detection of breast diseases. With the rapid advancement in computer and image processing technology with improved resolution today, it is worth the effort to revisit thermal imaging as a form of early detection of breast diseases.

Furthermore, thermal imaging is non-invasive, painless, passive and no radiation is involved. Thermography is the most efficient technique for the investigation of skin temperature distribution which provides information on both normal and abnormal breasts.[1] In order to perform quantitative studies, one needs to detect the edge and hot regions of thermal images. Detecting the boundary of thermal images is the first and most important step to be done on the image, for without finding the edge successfully, much of the information used in the diagnosis will not be accurate enough. One way in dealing with such problems is to use the snake or active contour model which can locate the boundary of an object by deforming an initial contour approximating the real boundary.

Snake or energy-minimizing active contour model was first proposed by Kass.[2] A snake is a deformable continuous curve whose shape is controlled by internal continuity forces and external image forces using an energy minimization model.[3] The internal forces come from within the curve itself, while external forces are computed from the image data. Internal forces act as a smoothness constraint, and external forces guide the active contour toward image features that are of interest. The technique of snake or active contour has become rather popular for a variety of applications, such as edge detection,[4] shape modeling,[5] segmentation,[6,7] and motion tracking.[8]

The snake has many advantages because the integration of energy is along the entire length of the snake. However, there are some difficulties with active contour algorithms, for example, the initial contour must be close to the true boundary, convergence is relatively slow and so forth. Based on Kass *et al.*'s basic idea,[2] active contour models with different energy functions have been proposed and processed by various optimizing methods. A fast algorithm and different curvature criteria were presented by Williams *et al.*[9] This greedy algorithm retains the improvements in stability. Wang *et al.*[3] proposed a three-stage scheme snake which optimizes both accuracy and convergence speed. Chan *et al.*[10] presented a two-step method which combines region and contour deformation to locate the boundary of an object from a designated initial boundary. Xu *et al.*[4] introduced another external force for active contour models which is known as gradient vector flow. The minimization is achieved by solving a pair of decoupled linear partial differential equations that diffuse the gradient vectors of a gray-level or binary edge map computed from the image.

Although these researches have made great improvement in algorithms and external forces of snakes, they still have some uncertainties in detecting the boundary of the current proposed thermal images. In this work, the authors improved the gradient vector flow snake. Firstly, these thermal images are pre-processed using median filtering, image differentiation, high-pass filtering and other image enhancement methods. The gradient vector flow snake is then used to detect the boundary of thermal images. Finally, one is able to analyze the thermal images and find the information needed for further diagnosis.

2. Methods

2.1. *Traditional snake*

Let $\mathbf{v}(s) = (x(s), y(s))$, $s \in [0, 1]$, be the parametric description of the snake. Its energy function can be written as

$$E = \int_0^1 [E_{\text{int}}(v(s)) + E_{\text{ext}}(v(s))]ds \tag{1}$$

where E_{int} and E_{ext} are internal and external energy respectively. The goal is to find a snake that minimizes Eq. (1).

In Eq. (1), the internal function can be written as

$$E_{\text{int}} = \frac{1}{2}\left[\alpha|v'(s)|^2 + \beta|v''(s)|^2\right] \tag{2}$$

where α and β are weighting parameters that control the snake's tension and rigidity respectively, and $v'(s)$ and $v''(s)$ denote the first and second derivatives of $v(s)$ with respect to s.

The external function in Eq. (1) can be derived from the image. The typical external energies designed to lead a snake toward edge can be written as four types

$$E_{\text{ext}} = -|\nabla I(x, y)|^2 \tag{3}$$

$$E_{\text{ext}} = -|\nabla[G_\sigma(x, y)^* I(x, y)]|^2 \tag{4}$$

$$E_{\text{ext}} = I(x, y), \tag{5}$$

and

$$E_{\text{ext}} = G_\sigma(x, y)^* I(x, y) \tag{6}$$

where $I(x, y)$ is a gray-level image, ∇ is the gradient operator and $G_\sigma(x, y)$ is a two-dimensional Gaussian function with the standard deviation σ .

Using the variational method, a snake that minimize the energy function of Eq. (1) must satisfy the following Euler equation

$$\alpha v''(s) - \beta v''''(s) - \nabla E_{\text{ext}} = 0. \tag{7}$$

Equation (7) can also be written as

$$\alpha x''(s) - \beta x''''(s) - \frac{\partial E_{\text{ext}}}{\partial x} = 0 \tag{8}$$

$$\alpha y''(s) - \beta y''''(s) - \frac{\partial E_{\text{ext}}}{\partial y} = 0. \tag{9}$$

A numerical solution of Eqs. (8) and (9) is presented by Kass.[2] The step involved is to discretize the equations and solve the discretized system iteratively.

2.2. *Gradient vector flow snake*

Xu *et al.*[4] define the gradient vector flow field as the vector field $\mathbf{V}(x, y) = (u(x, y), v(x, y))$. The energy function can be written as

$$E = \iint \left[\mu(u_x^2 + u_y^2 + v_x^2 + v_y^2) + |\nabla f|^2 |V - \nabla f|^2\right] dxdy \tag{10}$$

where ∇f is the gradient of an edge map $f(x, y)$ which is derived from the image $I(x, y)$. The parameter μ is a regularization parameter governing the tradeoff between the first term and the second term in the integrand.

The gradient vector flow (GVF) field can be obtained by solving the Euler equations

$$\mu \nabla^2 u - (u - f_x)\left(f_x^2 + f_y^2\right) = 0 \tag{11}$$

$$\mu \nabla^2 v - (v - f_y)\left(f_x^2 + f_y^2\right) = 0 \tag{12}$$

where ∇^2 is the Laplacian operator.

Kass[4] also presented the iterative solution to gradient vector flow as shown in the following equations

$$u_{i,j}^{n+1} = (1 - b_{i,j}\Delta t)u_{i,j}^{n} + r(u_{i+1,j}^{n} + u_{i,j+1}^{n} + u_{i-1,j}^{n} + u_{i,j-1}^{n} - 4u_{i,j}^{n}) + c_{i,j}^{\alpha}\Delta t \tag{13}$$

$$v_{i,j}^{n+1} = (1 - b_{i,j}\Delta t)v_{i,j}^{n} + r(v_{i+1,j}^{n} + v_{i,j+1}^{n} + v_{i-1,j}^{n} + v_{i,j-1}^{n} - 4v_{i,j}^{n}) + c_{i,j}^{\beta}\Delta t \tag{14}$$

where

$$r = \frac{\mu\Delta t}{\Delta x\Delta y}$$

and b, c^{α}, and c^{β} are coefficients which can be fixed in the entire iterative process.

2.3. *Proposed edge detection of thermal images*

By using traditional snake and gradient vector flow snake, the boundaries of breast thermal images that are required (Figs. 8–10, 15–17) however could not be determined satisfactorily.

In order to obtain an improved boundary of the thermal image, the following stages are suggested:

1. Derivative of the image by using Roberts cross-gradient operators to obtain the gradient image of this image.
2. Median filtering is used to process the gradient image.
3. The gradient image is sharpened using high-pass filters.
4. The thermal image is enhanced by the gradient image.
5. Derivative of the thermal image by using Roberts cross-gradient operators to obtain the new gradient image.
6. Process the new gradient image with high-pass and enhancement.
7. Carry out image transition for the new gradient image.
8. Detect the boundary of the new gradient image by using gradient vector flow snake.

By carrying out the above stages step-by-step, one can detect the boundary of the breast thermal image successfully. The proposed improved diagnosis of breast tumors is thus a fundamental and very important approach.

3. Results and Discussion

This section presents some examples of edge detection by using the following three methods: traditional snake, gradient vector flow snake, and the current proposed algorithm.

Case 1: Simple image

Figure 1 shows the original image, one can easily find its edge by using either the traditional snake or the gradient vector flow snake (Fig. 1).

The edge captured by gradient vector flow snake (Figs. 2 and 3) is better than the results obtained by traditional snake (Figs. 4 and 5) and the number of the iterative step required is also less for the gradient vector flow snake.

Case 2: Complex but sharp contact-thermogram

In this case, the thermal image is obtained from a contact breast thermogram system (encapsulated liquid-crystal SINOTEST M SP8). The original thermal image is rather clear and the boundary is evident as included in Figs. 6 and 7. Figures 8–12 present the various results captured by the three methods. The accuracy for both traditional and gradient vector flow snakes is unacceptable, whereas the agreement predicted by the current proposed approach is surprisingly good (Figs. 8–12).

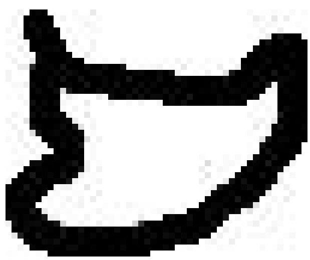

Fig. 1. Original thermal image of case 1.

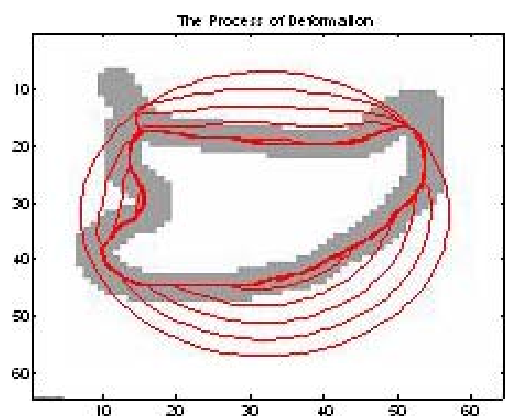

Fig. 2. Process of case 1: Deformation by gradient vector flow snake.

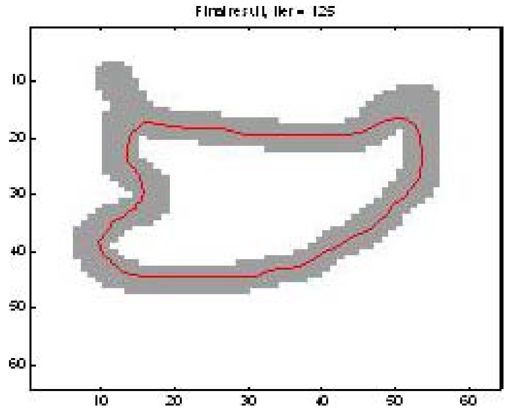

Fig. 3. Result of case 1: Edge detection by gradient vector flow snake.

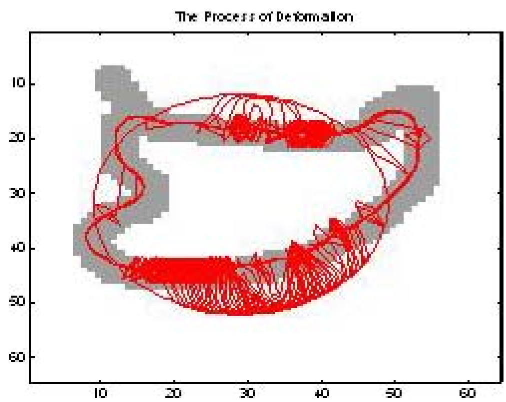

Fig. 4. Process of case 1: Deformation by traditional snake.

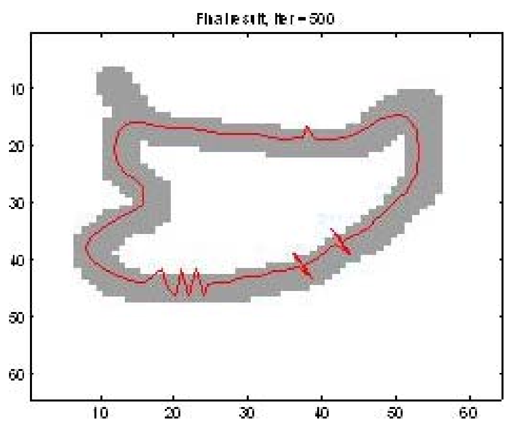

Fig. 5. Result of case 1: Edge detection by traditional snake.

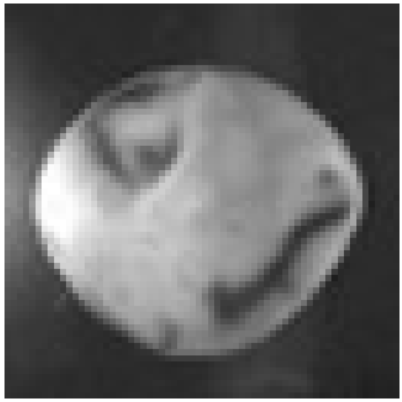

Fig. 6. Original thermal image of case 2.

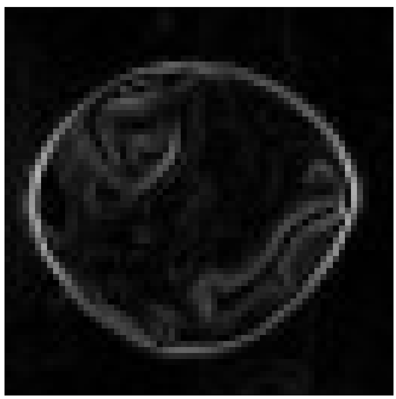

Fig. 7. Gradient image of case 2.

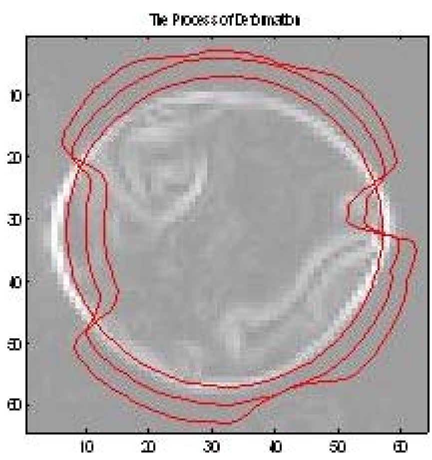

Fig. 8. Process of case 2: Deformation by gradient vector flow snake.

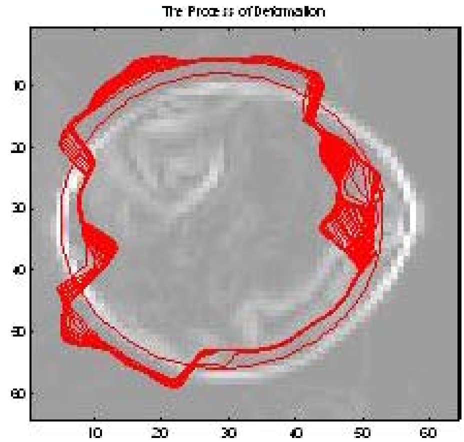

Fig. 9. Process of case 2: Deformation by traditional snake.

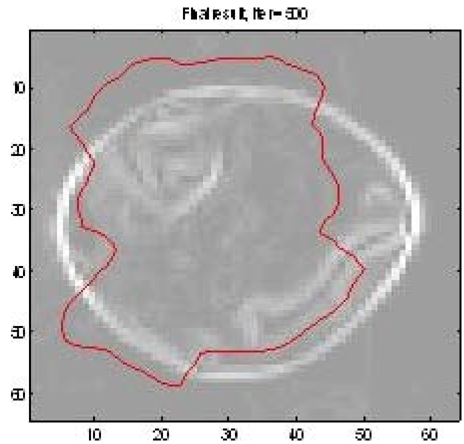

Fig. 10. Result of case 2: Edge detection by traditional snake.

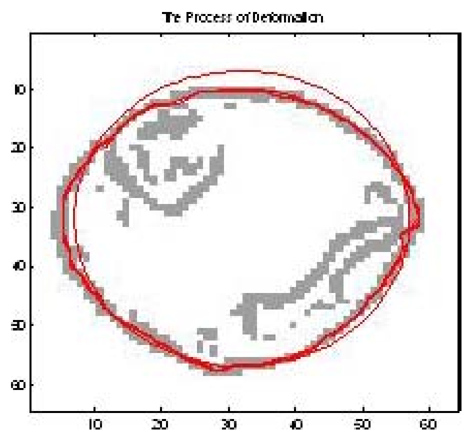

Fig. 11. Process of case 2: Deformation by current method.

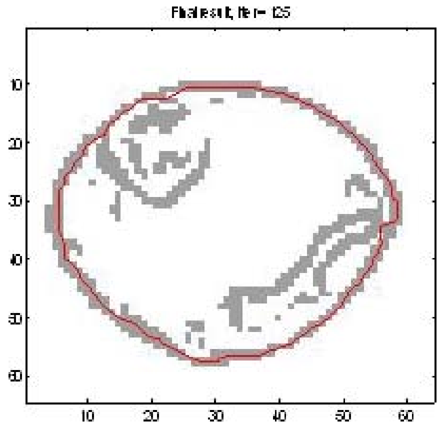

Fig. 12. Result of case 2: Edge detection by current method.

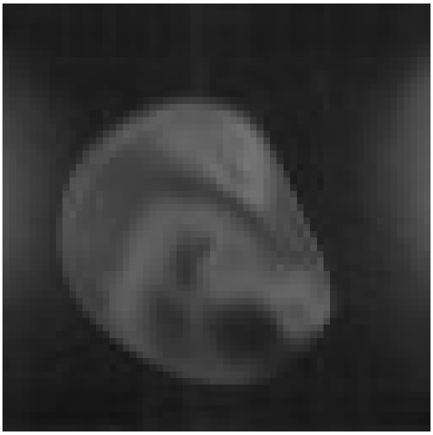

Fig. 13. Original thermal image of case 3.

Case 3: Complex and unclear contact-thermogram

The breast thermal image is obtained by the same system as in Case 2, but the image is not clear and the boundary is vague (Figs. 13 and 14). This thermal image is processed using traditional snake, gradient vector flow snake and the current methods. The different results captured are shown from Figs. 15 to 19. Similar observation to Case 2 is also obtained while Case 3 further illustrates that our proposed method is better when compared with the other two approaches even when the edge of the image is vague.

In summary, analysis of thermograms has been subjective in the past, resulting in the inconsistencies in the diagnosis of breast diseases by thermography. We

Fig. 14. Gradient image of case 3.

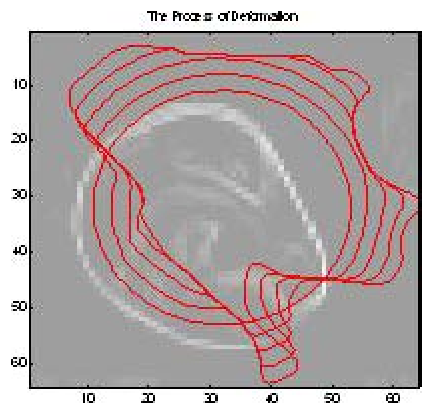

Fig. 15. Process of case 3: Deformation by gradient vector flow snake.

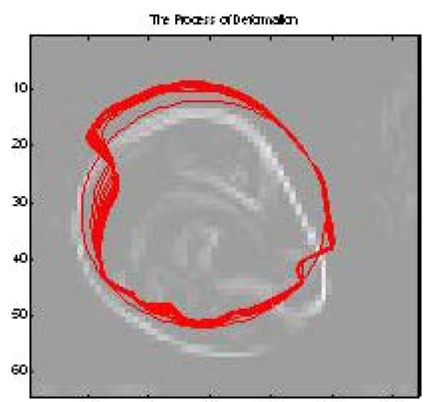

Fig. 16. Process of case 3: Deformation by traditional snake.

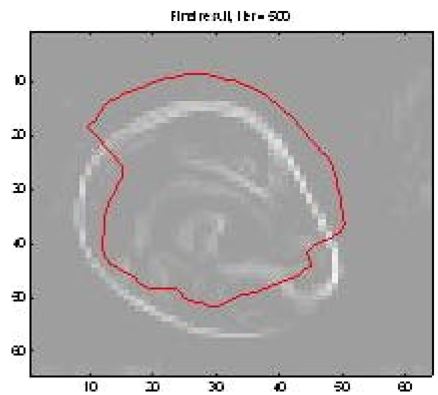

Fig. 17. Result of case 3: Edge detection by traditional snake.

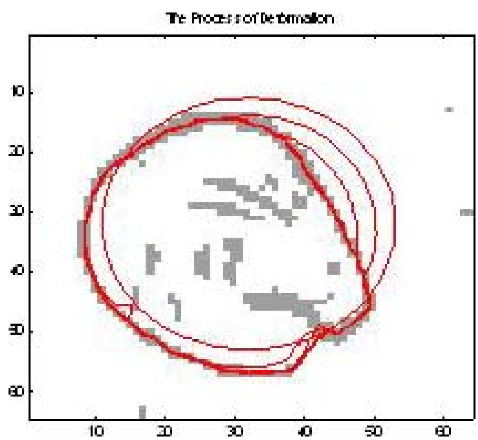

Fig. 18. Process of case 3: Deformation by current method.

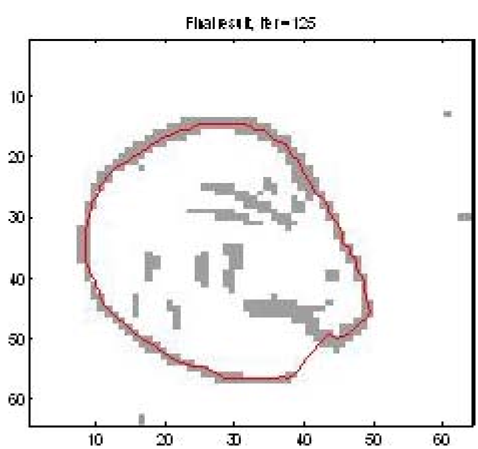

Fig. 19. Result of case 3: Edge detection by current method.

can further study the problem of subjective interpretation of breast thermograms and using thermography as an adjunct tool for breast cancer diagnosis. It is proposed that the thermograms should be taken within the recommended screening period, classified and analyzed in conjunction with an Artificial Neural Network (ANN).[11,12] Qualitative interpretation of thermal images could be done using active contours algorithm. The 256 $\times$ 200 pixels image can be segmented as one of the inputs to the ANN. As for quantitative analysis of the breast thermograms, the inputs of the ANN should be determined first and foremost for the successful classification and analysis of the thermograms based on the inputs suggested.[13]

4. Conclusions

Automatic identification of object and surface boundary of breast thermal images is a difficult and challenging task. Both the traditional snake and gradient vector flow snake failed to detect the boundary of these images successfully. In this work, a new method is proposed in conjunction with image pre-processing, image transition, image derivative, filtering and gradient vector flow snake. This novel method can easily detect the boundary of the breast thermal image with good agreement.

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