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Binary Connectedness based ANT Algorithm for Ultrasound Image Edge Detection

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Abstract

Congenital Heart Defects (CHD) are widely responsible for more than 10% of neonatal mortality in India. The objective of this work describes the sequential application of several techniques such as motion estimation, speckle suppression, image enhancement, image alignment and edge detection to delineate the edge structures of the fetal heart from clinical ultrasound images. The prominent image processing techniques used to localize the edge structures of fetal heart are Probabilistic Patch Based Weighted Maximum Likelihood Estimation (PPBMLE) based speckle noise suppression technique, Shock filter image enhancement technique and proposed modified edge detection with Binary connectedness based ANT algorithm. The main contribution of the proposed ANT algorithm for edge detection uses binary connectedness property among pixel intensities to efficiently update the heuristic information of ANT algorithm. The quantitative performance merit prove that the sequential application of the above mentioned image processing techniques was predominantly useful in delineating the ultrasound fetal heart structures and interpret pathophysiologic biomarkers from images.

Keywords: Ant Colony Optimization, Binary Connectedness, Congenital Heart Disease, Detection Morphology, Edge

1. Introduction

Congenital Heart Disease (CHD) is one of the most common causes of prenatal birth defects. Earlier diagnosis of CHD aids in maximizing the chance of neonatal mortality. Owing to the nature of poor contrast in ultrasound imaging modality, it captures the biological structures with missing boundaries. In this scenario, it becomes very difficult for the untrained obstetricians and gynecologists to deduce clinically diagnosable details from ultrasound images[1]. Delineating fetal heart chamber boundary is one of the most important processes to identify the presence of heart defects in ultrasound images. Thus, carrying out edge detection as a pre-processing step for realizing the automated image analysis and decision support systems is essential. Performing edge detection in fetal ultrasound images is non-trivial because, the nature of fetal heart chamber wall is very thin along the atrial and ventricular septum. So obviously this situation provides higher impact on contriving unique method to improve the automatic delineation of biological structures from ultrasound images.

The proposed work involves three main steps. Firstly, despeckling as the process of pre-processing was performed using PPBMLE proposed by [2]. Secondly, proposed work uses the Shock filter generalized by [3] to enhance the sharp boundaries of the image objects as it holds several advantages. As a final step to process the clinical ultrasound image, the proposed Binary connectedness based ANT algorithm for edge detection is used to delineate the fetal heart structures. The proposed ANT algorithm is the generalization made to ANT colony optimization based

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edge detection method proposed by [4] and the ant algorithm based edge detection is modified in such a way to make use of the binary connectedness rules for updating the heuristic information.

Literature in recent years report that, several generalizations have been made to the basic ACO based edge detection algorithm. Many Fuzzy logic based approaches, Fuzzy derivatives and statistical computational parameters have also been used to modify the basic ACO algorithm in the form of hybrid method for image edge detection [5-7] Proposed a heuristic based ACO edge detector which identifies the ideal edge pixels by comparing it with the template edge structures. Jing et al. proposed a modified ANT colony system based edge detection method in which the ants move in the image driven by local variation of image intensity values to identify the edge pixels[8]. Also many edge linking algorithms have been reported in literature to detect edge structures of the images meaningfully. [9] Proposed an edge linking methodology with the use of mask to calculate the cost of edge linking points

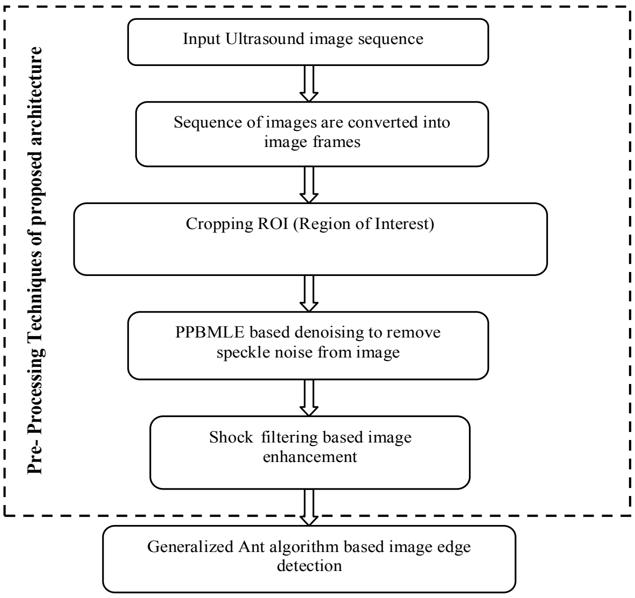

Figure 1. Proposed system architecture.

2. Methodology

This section describes about the step by step approach of various image processing techniques adapted to perform this experimental study. Figure 1 shows the proposed system architecture. Ultrasound scanning of fetal heart is captured as video and those sequences can be converted into frames as first step. The visual quality of ultrasound fetal heart image has low signal to noise ratio and hence the robust framework of despeckling technique namely PPBMLE denoising approach proposed by [2] was applied to remove the speckle noise.

Shock filter oriented image enhancement makes use of the partial differential equation based morphological techniques such as dilation and erosion of the image. The shock filtered image region becomes flattened, which explicitly helps in yielding piecewise segmentation progression. This enhancement technique introduces sharp discontinuity between two distinct regions of image namely the object and background. Hence this shock filtering technique comforts the process of performing edge sharpening in the image. The improved version of shock filter proposed by [3] was used in this experimental study which makes the image more suitable for application of ANT algorithm based edge detection to extract the fetal heart edge structures. The shock filter diffuses the image along parallel directions across the edges and creates a shock perpendicular to the edge region. Shock filter is defined by

$$I_t = -sign(v_\eta)|\nabla I| \qquad (1)$$

$$v_\eta = K_\sigma * I \qquad (2)$$

Where I is the 2-dimensional image, $v_{\eta\eta}$ is the directional smoothing operator with K as Gaussian smoothing kernel, σ as Standard deviation, "$*$" as Convolution and $|\nabla I| = (I_x, I_y)$ is the image gradient in x and y direction

2.1 Binary Connectedness based ACO Methodology

The main use of edge detection is to extract the object boundaries in an image. Several high level image processing tasks such as object recognition, feature extraction and image classification highly depends on the edge detection as the major fundamental task. This proposed work makes use of modified ant algorithm with binary connectedness to perform edge detection. The prominent contribution of the proposed method is to combine the framework of Ant algorithm with morphological operations to trace out the edges of the input clinically preprocessed ultrasound image. This proposed method of edge detection is efficient in detecting and linking the edge pixels.

The primary goal of ACO based image edge detection algorithm is to consider the edge pixels of image region as source of food during the searching phase and solution construction phase to perform edge detection. To achieve this goal, the artificial ants have to be distributed intelligently over the connected graph-like search space of 2D image region. During the iterative process, the ants traverse in each limited image region by laying the pheromone chemicals in the graph nodes to identify the edges and generate the detected edge image as solution. The search process starts by considering a group of ants which are made to split in search of edge pixels in the graph of sub image region Sa,b with center pixel located in a, b coordinates. The limited search space visible for the ants to search and to identify the relative edge pixels are shown in Figure 2.

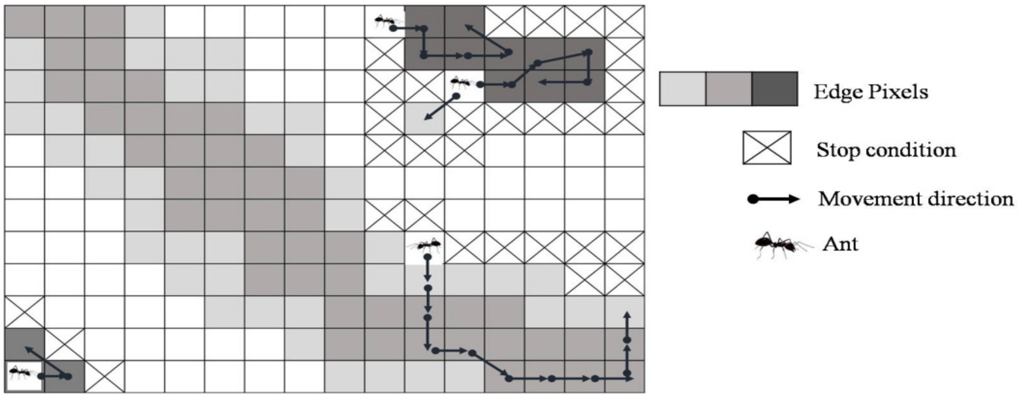

Figure 2. 2D image region as Search space with ants' traversal.

The two factors of probability transition matrix are ant movement attractiveness or heuristic information and pheromone information. In order to reduce the time consumption of the search process, the various steps involved in the proposed method helps the ants to identify the edge pixels quite easily. The proposed method is used to improve the intelligence of the artificial ants to select suitable paths while traversing in the search space to identify the edge pixels and link the broken edges meaningfully. Various steps involved in the proposed edge detection are as follows:

Step 1: Morphological Gradient Image Computation

The gradient image provides more information about image object boundaries and hence it is optimal to compute image gradient to solve the problem of edge detection.

The process of computing gray scale morphological gradient of input image $I_G(m,n)$ composes of two essential operations namely gray scale dilation operation denoted by $I \oplus S$ and grayscale erosion operation denoted by $I\Theta S$ [HSZ 87]. This gradient computation of the input image emphasizes the object edges alone with stronger gray level transitions. The grayscale morphological gradient image is defined by

$$I_G(m,n) = \{[I \oplus S] - [I\Theta S]\} \tag{3}$$

Step 2: Converting Morphological Gradient Image into Binary Image

The morphological gradient image $I_G(m,n)$ is then converted into a binary image $I_B(m,n)$

This operation helps to do the extract binary connectedness properties of pixel intensities in the limited search space. The image is binarized at a particular gray level 't' which can be chosen automatically by using Otsu method.

$$I_B(m,n) = \begin{cases} 1; & I_G(m,n) \geq t \\ 0; & I_G(m,n) < t \end{cases} \tag{4}$$

Step 3: Computation of Number of Boundaries with Binary Connectedness in Search Space

In order to improve the ant algorithm based edge detection and to update the heuristic information of the proposed ANT algorithm, the number of boundaries in the binary image $I_B(m,n)$ has to be computed from gradient magnitude image. There exists a binary connectivity between any two pixels say i and j, if they belong to same connected component in the 3x3 kernel. Edges characterize the noticeable boundary features of objects in the image. These boundaries can be traced out from a binary image in the form of identifying intensity variation from 0 to 1 and from 1 to 0 respectively.

Step 4: ANT Searching Process

The heuristic information is updated with the help of normalized pixel values of morphological gradient image $I_G(m,n)$ and the number of boundaries in the binary image $I_B(m,n)$. Availability of more than one morphological boundary N_b in the 3x3 kernel search space signifies the presence of edge pixels and non availability of morphological boundary region in the search space signifies the absence of edge pixels. The ants are attracted to move further with the availability of N_b signifying the presence of food i.e., the presence of edge pixel intensities in the search space. If the boundary region is not identified in the search space denotes that the stopping criteria for the ant movement in current iteration, then the ant located at the current position will die and stop moving further The presence of edge pixels in the neighbourhood can be confirmed through heuristic matrix by identifying the boundary trace of binary image region. Thus the proposed ANT algorithm updates the heuristic information using

$$\eta_{m,n} = \begin{cases} \dfrac{I_{\max} - I(m,n)}{I_{\max}}; & If \quad I_G(m,n) \geq \theta \,\&\, N_b \geq 1 \\ 0; & Otherwise \end{cases} \tag{5}$$

In the above equation $I_{\max}$ represents the maximum gray level intensity value in the search space image and $I(m,n)$ represents the intensity value centered with m,n co-ordinate location. θ represents the normalized intensity value highlighting the edge features of morphological gradient image and N_b represents number of boundaries in the binary image. In this morphology based ant algorithm method, the movement of ants' position from one pixel to another pixel is decided by the Probability transition

matrix $p_{m,n}$ .The term transition probability is defined by

$$p_{m,n} = \frac{[\tau_{m,n}]^{\alpha}[\eta_{m,n}]^{\beta}}{\sum_{n\in\Omega_m}[\tau_{m,n}]^{\alpha}[\eta_{m,n}]^{\beta}}; \quad if \quad n \in \Omega_m \tag{6}$$

The pheromone information provides the facts about the choice of path. At the end of strolls, the artificial pheromone trials are updated as

$$\tau_{m,n}^{new} = (1-\rho)\tau_{m,n}^{old} + \rho\tau_{m,n} \tag{7}$$

where ρ is represented as pheromone evaporation rate. Finally at the end of solution construction phase, the ant decides the presence of edge pixels in the input image by binary decision at every pixel position by truncating the final pheromone matrix.

3. Quantitative Evaluation

The performance analysis of proposed method uses Pratt's Figure of Merit (FOM) to numerically evaluate the quality of edge detection process. This evaluation parameter measures the distance between the contours of the ground-truth image and edge detected test image[10]. The FOM parameter is defined by

$$FOM = \frac{1}{\max(N_{GE}, N_{TE})}\sum_{j=1}^{N_{TE}}\frac{1}{1+\alpha d_j^2} \tag{8}$$

In the above equation, represents the distance between edge pixels in test image from nearest original edge pixels in ground-truth image. N_{GE} and N_{TE} represents the number of edge pixel points in ground-truth and test image respectively. α is the empirical calibration parameter and $\alpha = 1/9$. The quantitative analysis of proposed method in comparison with conventional method is given in Table 1.

4. Results and Discussion

This paper describes the various image processing techniques to detect the edges of the ultrasound fetal heart structures. Though the scanned ultrasound images are speckled and have low signal to noise ratio, the various processing techniques used in this experimental study makes the clinical ultrasound image suitable for high level image processing such as classification, object recognition etc.

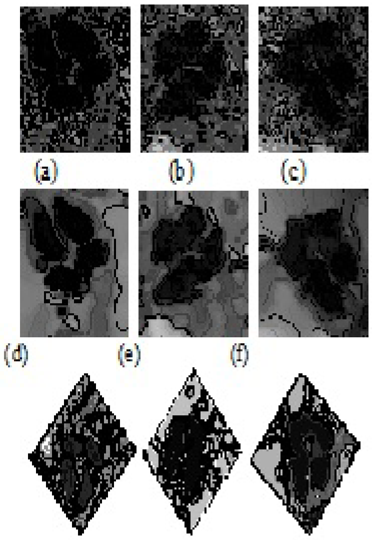

Figure 3. (a) (b) (c) Fetal heart images; (d) (e) (f) PPBMLE despeckled images; (g) (h) (i) Images Enhanced by Shock Filtering method.

Figure 3 shows the ultrasound image processed using PPBMLE based despeckling, Shock filtering based image enhancement and image alignment processes applied for ultrasound image respectively with Jing Tian method of ACO algorithm based edge detection and Proposed ACO method of edge detection results. To declare the efficacy of the proposed edge detection method, its performance is compared with Jing Tian ACO based edge detection method. The performance metric chosen for evaluating the performance is Pratt's figure of merit. Table 1 proves the efficacy of proposed method and it outperforms the conventional method.

5. Conclusion

Experimental results of the proposed work clearly delineate the fetal heart chambers from the clinical ultrasound images. Before applying these techniques, the ultrasound image is unfavorable to draw a clear patho-physiological diagnostic result. Thus the proposed work would be much useful for assisting the radiologists to make diagnostic decisions. Also it is obvious that this experimental study is much useful in designing the CADSS declare clinical diagnostic results. The future work is to classify the fetal heart image into normal and abnormal category.

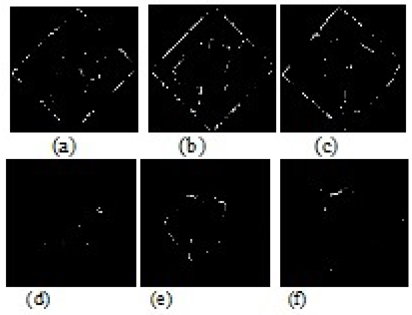

Figure 4. (a) (b) (c) Jing Tian Edge detected results for Fetal heart images 1, 2 & 3; (d) (e) (f) Proposed results for Fetal heart image 1, 2 & 3.

Table 1. Quantitative evaluation with Pratt's Figure of Merit

SI.NO	Image Name	Jing Tian method	Proposed Ant method
1	Heart image 1	0.4352	0.8413
2	Heart image 2	0.4782	0.8659
3	Heart image 3	0.4633	0.9106

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