International Journal of Bio-Science and Bio-Technology
Vol.7, No.1 (2015), pp.1-10
http://dx.doi.org/10.14257/ijbsbt.2015.7.1.01

Appendix Analysis from Ultrasonography with Cubic Spline Interpolation and K-Means Clustering

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Abstract

Diagnosis of appendicitis is an area of interest in clinical research since long. Specifically speaking, accurate diagnosis of acute appendicitis is important since it needs subsequent surgical operations and particularly if the patient is a pregnant woman or a child. However, after ultrasonography, medical expert's naked-eye examination is finally done, which is being practiced till date. Although developing full automatic appendicitis diagnosing software is a far reach goal to achieve since there are still many techniques and theories yet to be developed, but an automatic appendix extracting software can definitely developed in near future, which is now the interest of study of many researchers.

In this paper, a method is proposed to extract appendix automatically from a ultrasound image. The proposed method uses various image processing techniques with morphological features of appendix. The advantages of Cubic Spline interpolation for extracting fascia area and subsequently applying K-Means clustering for extraction of appendix from the image is being discussed in this paper.

Experimental result shows the appendix extracted through this method is acceptable to medical expert.

Keywords: *Appendix, Ends-in Stretching, Region Labeling, Cubic Spline, K-Means Clustering*

1. Introduction

The appendix is a wormlike intestinal diverticulum extending from the blind end of the cecum; it varies in length and ends in a blind extremity [1]. When it has an inflammation by bacteria or other reasons, the wall of the appendix become distended, causing malicious growth of intra-luminal pressures which causes appendicitis.

Appendicitis is classified into early appendicitis, gangrenous appendicitis, gangrenous appendicitis, chronic appendicitis and acute appendicitis according to its various stages of growth [2].

Proper diagnosis of the acute appendicitis is important since it often leads the removal of the inflamed appendix, either by laparotomy or laparoscopy. Secondly, even if it is not acute, it may develop into other complications and the mortality is relatively high if treatment is not done in time.

ISSN: 2233-7849 IJBSBT

A typical process of treating appendicitis is that after confirming the pain from lower-right abdomen, a blood test is required to observe the change of white blood cell rate followed by urinalysis to exclude the possibility of urolithiasis and nephropyelitis. Then the CT and/or ultrasonography finally verifies the state of appendix to diagnose the pain occurred by the appendicitis by naked eye examination by medical practitioners.

Current research reveals that the diagnosis of appendicitis by CT and ultrasonography were correlated with clinical or pathologic diagnosis but not matching all the time. Thus, the reevaluation of CT findings by ultrasonography could avoid misdiagnosis of appendicitis on CT and improve diagnostic accuracy of acute appendicitis [3].

Further to add, there exists a high level of reluctance of using radiological test to young children or pregnant women. Thus, ultrasonography is often used in diagnosis of appendicitis in such cases. However, even such diagnosis by ultrasonography should be treated carefully since it may cause unnecessary operations to remove inflamed appendix for children [4].

Usually, the final step of such diagnosis is done by naked-eye examination of ultrasound image with chosen set of predictor attributes. Undoubtedly, the accuracy of such naked eye examination suffers from the subjectivity of practitioners and their experience level, fatigue etc.

Therefore, there is growing need for a computerized automatic decision tool to extract questionable appendix part with necessary predictor attributes. Unfortunately, there are very few tools available for the practitioners to use with credibility up to date.

Probably, the first step of building such decision tool by computer scientists could be an automatic segmentation of appendix from ultrasonography. Even in this area, we have not enough study yet since it includes many image processing tricks and/or AI techniques.

A study [5] uses various histogram thresholding techniques but failed to extract the whole appendix from the image. Another study [6] uses fascia as a predictor of the location point of appendix candidate and uses some intelligent techniques to determine the appendix boundaries with various image processing methods. However, it suffers from various sources of noises occurred during the process and the performance depends on the correct extraction of fascia, which sometimes fails due to these reasons.

In this paper, another automatic appendix extraction method is proposed [6] with various image processing techniques, which overcomes previous limitations.

The main objective of this paper is on removing fascia area correctly during the noise removal process. It has been observed from our studies that the previous method often fails to do the removal of fascia area correctly during the noise removal process, because the fascia lines are often disconnected due to the low dispersion of brightness in the image, which causes false negative extraction of appendix. Thus, a cubic spline interpolation is proposed at that stage.

After removing fascia parts successfully, K-means clustering technique is applied to this image to extract the target appendix. With this pixel clustering techniques, the appendix area is extracted with more contrast.

Figure 1 demonstrates the overall process of the proposed method. End-in Search stretching and Min-Max binarization is used for enhancing the brightness contrast reported in [6] and therefore other parts of the system is elaborated in detail in this paper.

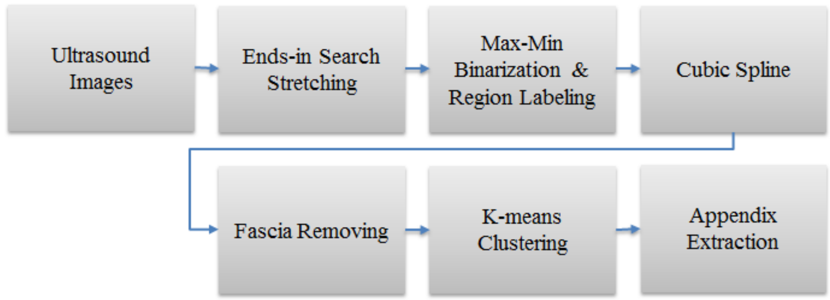


Figure 1. Process of Extracting Appendix

2. Removing Fascia Area

As shown in Figure 2, abdomen ultrasound image consists of image filming information on the above and measurement information on the right and the abdomen image at the center. In the abdomen image, there are fascia area including muscles and appendix area below the fascia. Appendix has the shape of a circle or flat oval.

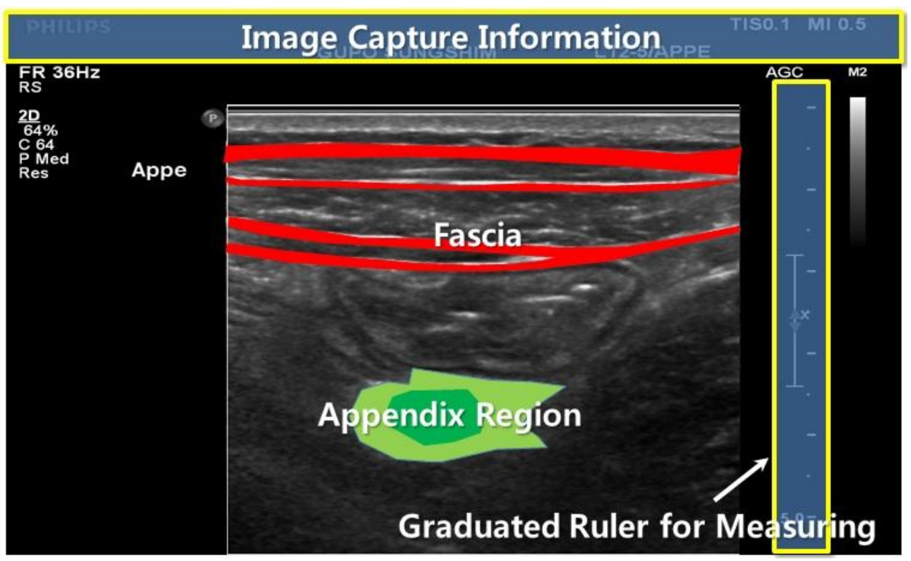
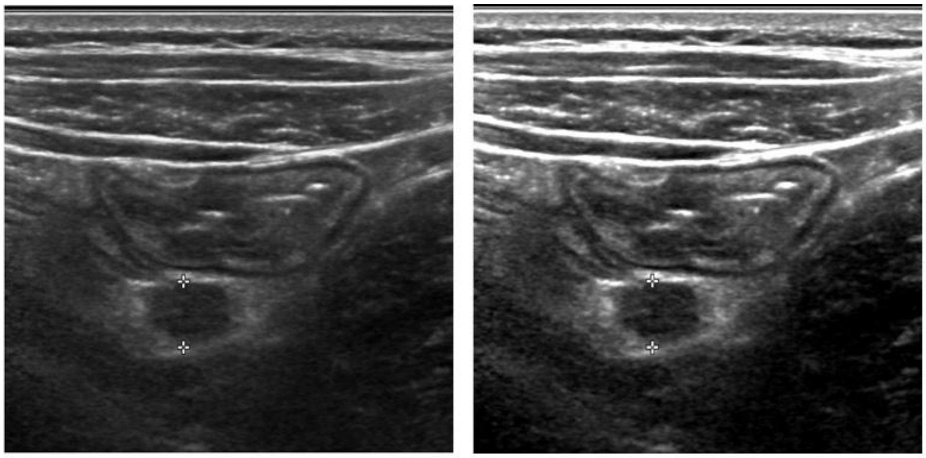


Figure 2. Abdomen Ultrasound DICOM Image

First, we apply End-in Search Stretching is applied [7] to enhance the brightness contrast using the formula (1) since the abdomen image is usually dark and not sufficient to discriminate fascia, muscles, and other areas as it is.

$$S_{(x,y)} = \begin{cases} 0 & P_{(x,y)} \leq Min \\ 255 \times \dfrac{P_{(x,y)} - Min}{Max - Min} & Min < P_{(x,y)} < Max \\ 255 & P_{(x,y)} \geq Max \end{cases} \tag{1}$$

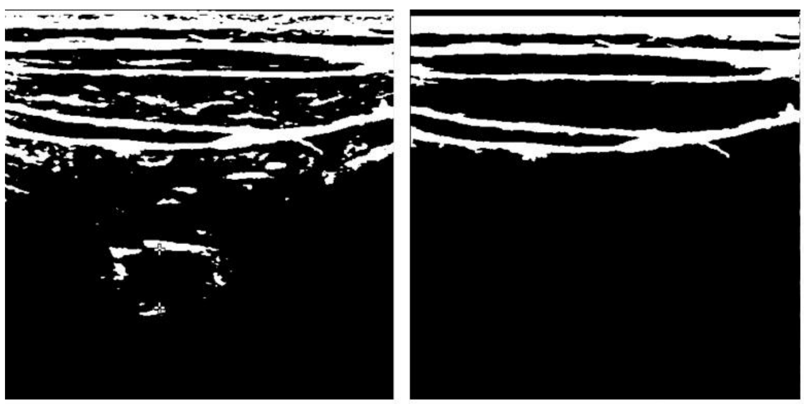
where *Min* and *Max* are thresholds and *P(x, y)* denotes the brightness value in the original image and *S(x, y)* denotes the result. Figure 3 shows the effect of Ends-in Search Stretching.



(a) Original Image (b) Ends-in Search Stretching

Figure 3. Effect of Ends-In Search Stretching

In Figure 3(b), Max-Min binarization is applied first and then region labeling method is applied recursively [8] to connect related pixels. If the connected object is too short, it is regarded as noise thus they are removed and the result is shown as in Figure 4. The experimental threshold in this paper is 1500.



(a) Applying Max-Min Binarization (b) Region Labeling and Noise Removal

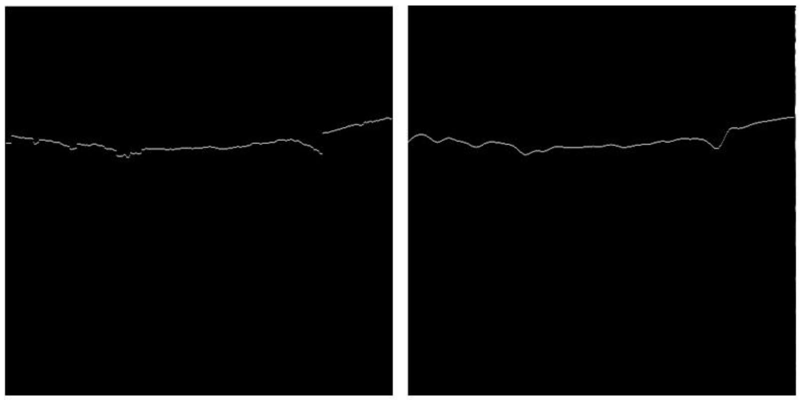
Figure 4. Effect of Region Labeling

Unfortunately, the binarized noise-less image may have disconnected fascia area due to the brightness difference of that area. In order to reconnect them, Cubic Spline interpolation is applied [9].

Cubic Spline interpolation connects two points on the boundary when formula (2) is satisfied.

$$\begin{cases} S''_{n-1}(x_n) = S''_0(x_0) = 0 & \\ S''_{i-1}(x_i) = S''_i(x_i) & i = 1,2,3,\cdots,n-1 \\ S'_{i-1}(x_i) = S'_i(x_i) & i = 1,2,3,\cdots,n-1 \\ S_{i-1}(x_i) = S_i(x_i) = y_i & i = 1,2,3,\cdots,n-1 \end{cases} \tag{1}$$

First two equations are hard constraints but the next two are soft constraints for smoothing. Since we know that the target appendix is located below the bottom of fascia, cubic spline interpolation is applied to the bottom fascia line and the result is shown as in Figure 5.



(a) Candidate Fascia Boundary (b) After Cubic Spline Interpolation

Figure 5. Effect of Cubic Spline Interpolation

3. Extracting Appendix Object

After removing fascia area, K-means clustering technique is applied [10] to separate appendix.

K-means clustering is an unsupervised learning algorithm to classify each data into K clusters to minimize the variance of distances.

Step 1. Initialize as formula (1)

- Set the number of clusters k
- For each cluster, set the initial center color value at random

$$\{C_i(m), C_1(m), C_2(m), \ldots, C_k(m)\} \tag{1}$$

where $C_i(m)$ denotes ith cluster's center color value in mth repetition:

Step 2. Distribute pixels to clusters

- For every pixel x^p, distribute it with respect to the difference between the clusters with formula (2)

$$\begin{aligned} &if \quad \left|x^p - c_j(m) \,|\, x^p - c_i(m)\right| \ (i = 1, 2, \cdots, k,\ i \neq j) \\ &then \quad x_p \in S_j(m) \end{aligned} \tag{2}$$

$S_j(m)$: jth cluster in mth repetition

Step 3. Derive new center

- Using newly formed clusters, new center value is determined by formula (3)

$$c_j(m+1) = \frac{1}{N_j} \sum_{x^p \in S_j(m)} x^p \tag{3}$$

Step 4. convergence Test

- Compute the change of center for all clusters

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- If the sum of difference is sufficiently small, the
  classification is finished
- Otherwise go to step 2 until step 4 is satisfied
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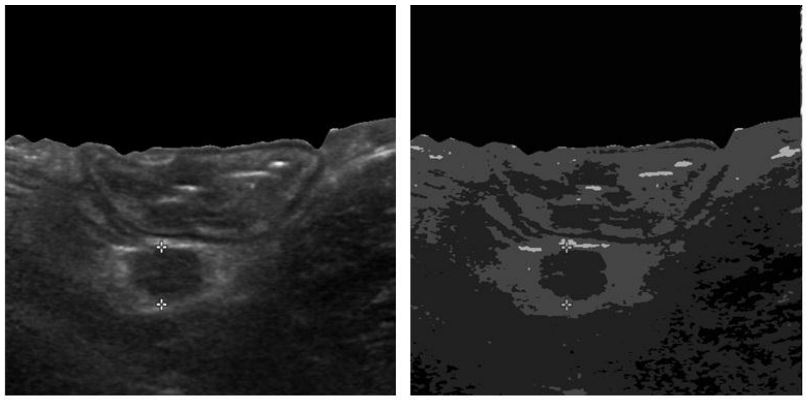
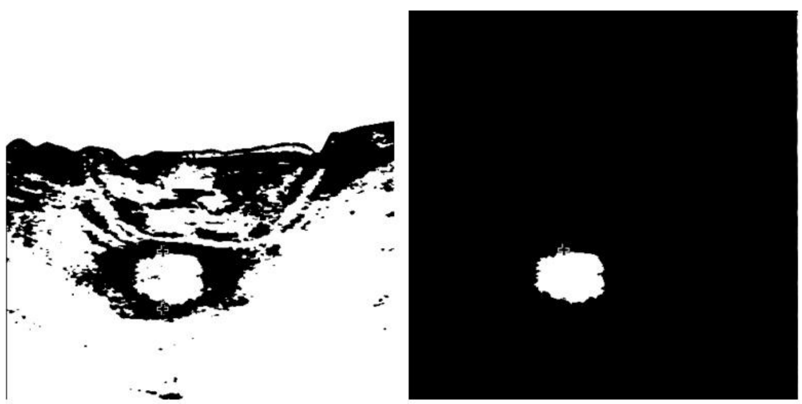
The effect of K-means clustering is shown as Figure 6.



(a) Candidate area (b) K-Means Clustering Applied

Figure 6. Effect of K-means Clustering

The final step of extracting appendix is applying erosion operation to remove noises and labeling each pixel by region labeling as pixels of the same object have the same label. Using the morphological characteristic that the appendix is located below the fascia with relatively higher brightness among organ area and has the flat oval shape, we extract an object located near center with object size less than 3000 in this paper as shown in Figure 7.



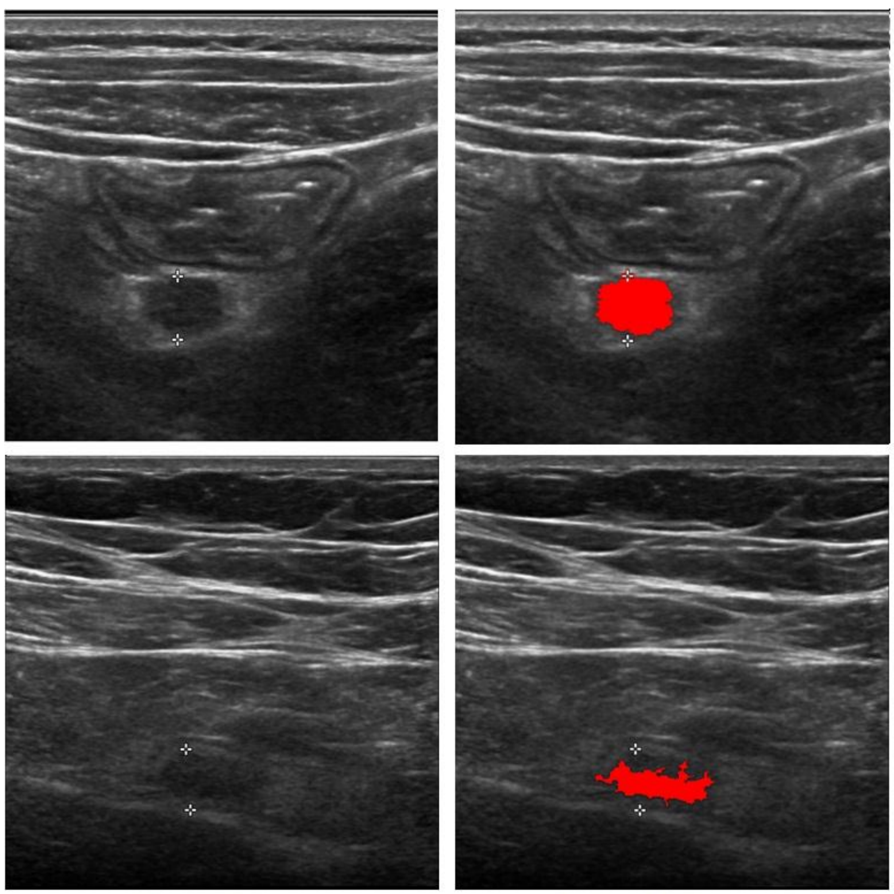
(a) Low Brightness Region (b) Applying region labeling

Figure 7. Extracting Appendix

4. Result Analysis

The system is implemented in Visual Studio 2010 C# with Intel(R) Core(TM) i7-2600 CPU @ 3.40GHz and 4GB RAM PC. The actual system gives some characteristic features of extracted appendix as shown in Figure 8. Some of appendix extraction examples by proposed method are shown in Figure 9.

Figure 8. System Screenshot



(a) Original image (b) Appendix Extracted

Figure 9. Extracting Appendix

The extracted results were verified by medical expert and in general they were acceptable. However, the proposed method failed to extract the appendix correctly sometimes for particular cases as shown in figure 10. In this case, appendix shape is not very clearly viewed as an oval and instead the system extracted the patient's ascites of a significant size.

5. Conclusion

In this paper, a method is proposed to extract appendix from ultrasound image automatically with various image processing techniques and K-Means clustering.

In the previous study [6], we had used the technique to find out appendix below fascia and remove it first from the region of interest. Here, the bottom fascia lines were carefully treated with Cubic Spline interpolation such that the lines were connected correctly since the previous study often failed to extract fascia lines thus led incorrect appendix extractions. Then K-means clustering is applied to classify pixels into same objects of their labels such that the appendix could be extracted based on its morphological features.

Extracted appendix results were shown to medical experts and verified as acceptable in most cases, except for some particular case where patient's ascites of a significant size may mislead the system to extract it as an appendix.

Since this effort is just the first step toward developing automatic appendicitis diagnosis software to assist medical practitioners, the proposed system needs to be developed further to treat various medical cases in our future plan of research.

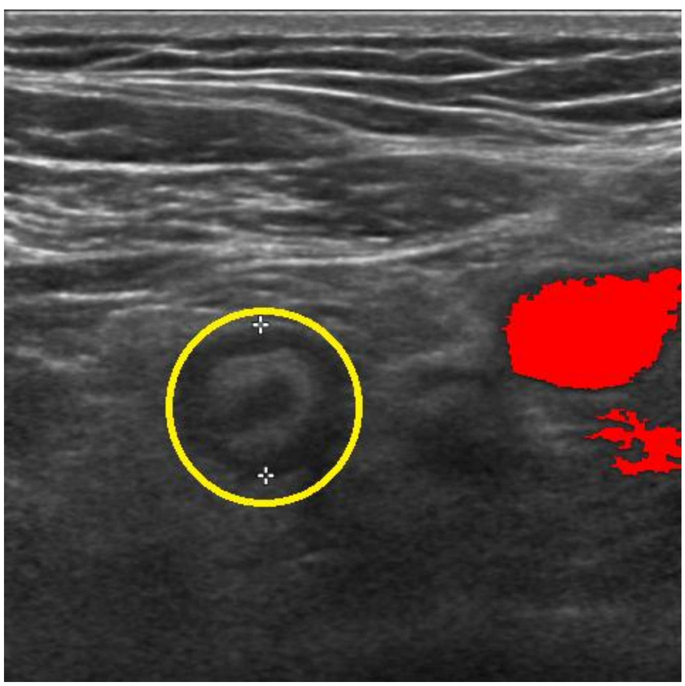


Figure 10. Failed Extraction Case

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