CHAPTER 4

Research Designs and Methods

This chapter provides research designs and methods of the proposed techniques for supporting cardiomegaly diagnosis. The methodology of this research is divided into 6 sections. Section 4.1 describes the method used to find the reference position of the heart. Section 4.2 describes the method for finding ribs position. Section 4.3 describes the transverse diameter measurement method. Section 4.4 describes the frame selection technique. Section 4.5 describes the method of heart structure segmentation and section 4.6 describes the cardiac diameter measurement method. [26]

Ultrasound videos used as input for this research were provided by Professor Dr. Theera Tongsong, a medical doctor at Maharaj Nakorn Chiangmai Hospital. They were the ultrasound video of fetal heart during the first half of pregnancy (11-20 weeks of gestation), that contain both normal and abnormal heart sizes. This research intends to create an automatic cardiac diameter (Cd) and thoracic diameter (Td) measurement algorithm from the ultrasound video of four-chamber view to help physicians detect cardiomegaly in fetus. To measure the cardiac size, the video frames of the end-diastolic stage are required since the heart has the largest size. Basically, the fetus heart rate is 120-160 bpm or 2-3 bps [24] which means, heart beats 2-3 times within a second. Therefore, the frames obtained from the first second of ultrasound video containing at least 2 frames of the end-diastolic stage are sufficient for cardiac measurement. In this study, the number of input frames depends on the video frame rate that is in the range of 20-99 frames/sec.

To find Cd and Td from an ultrasound video, we needed to determine the region of interest (ROI). In our research, ROI1 represented the area that contained heart chambers which presented a high motion in the video. ROI1 would be used in many other steps of our experiment as a heart reference position. Rib positions indicated by the threshold method were used for measuring Td and finding ROI2 which was the region that covered all the heart area. The frames of fetal heart with low motion were selected. They were frames in the end-systolic and end-diastolic stages. Then patch-based possibilistic C-mean (PCM) was applied only to ROI2 for segmenting heart structure. In order to measure cardiac size, interventricular septum line (IVS) in the heart structures needed to be located. Finally, the Cd was obtained from the frame containing the largest cardiac size and used to compute the CT ratio. The flowchart of the proposed algorithm for cardiomegaly detection is shown in figure 4.1.

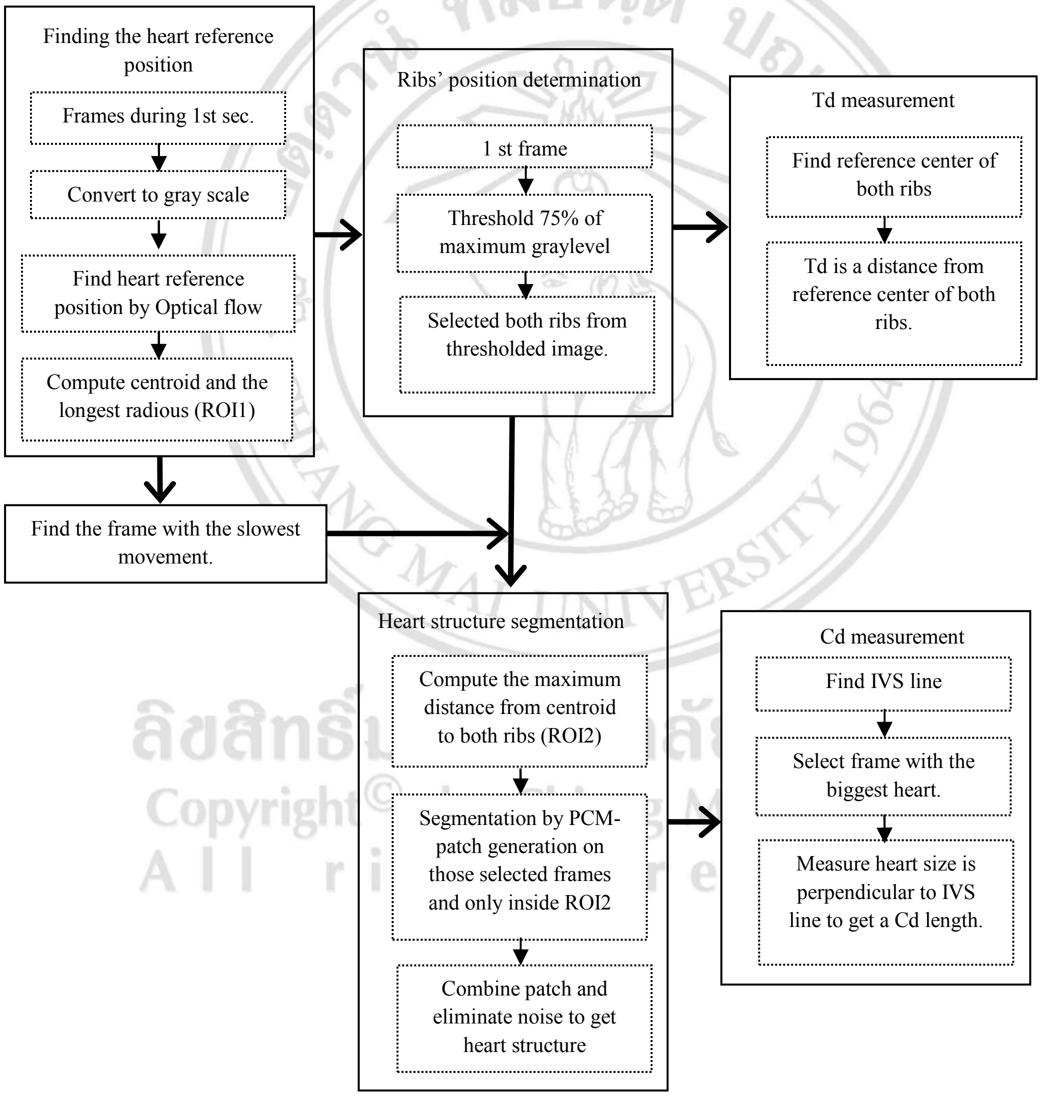


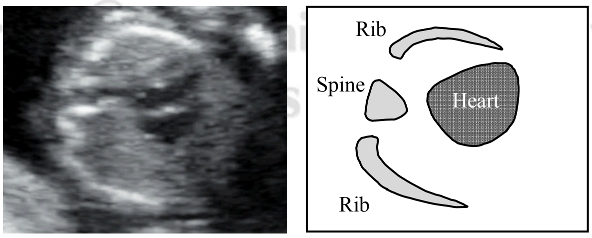
Figure 4.1 Flowchart of automatic cardiomegaly detection algorithm.

4.1 Finding the Heart Reference Position

To find the heart reference position, the RGB color images of all frames in the first second of the video were converted into gray scale images (Figure 4.2). After that the Horn-Schunck's motion estimation method was applied to the sequence of grayscale images to find the most movement area, a heart chamber area. Although, in these short time frames (1 second), there was a very slight movement of the fetus body, only heart area continuously moved. The large magnitude value could be seen only in the most movement area as shown in figure 4.3(a). Then the Otsu's method was applied to binarize each magnitude velocity field image. However, the binarized result of each motion estimation image was not enough to locate heart reference position, due to a very little movement within each magnitude velocity field image. Therefore to enhance the most movement area, the binarized results were added together (Figure 4.3(b)) and Otsu's method was applied again to obtain the heart reference area. An example of the heart reference area is shown in figure 4.3(c).

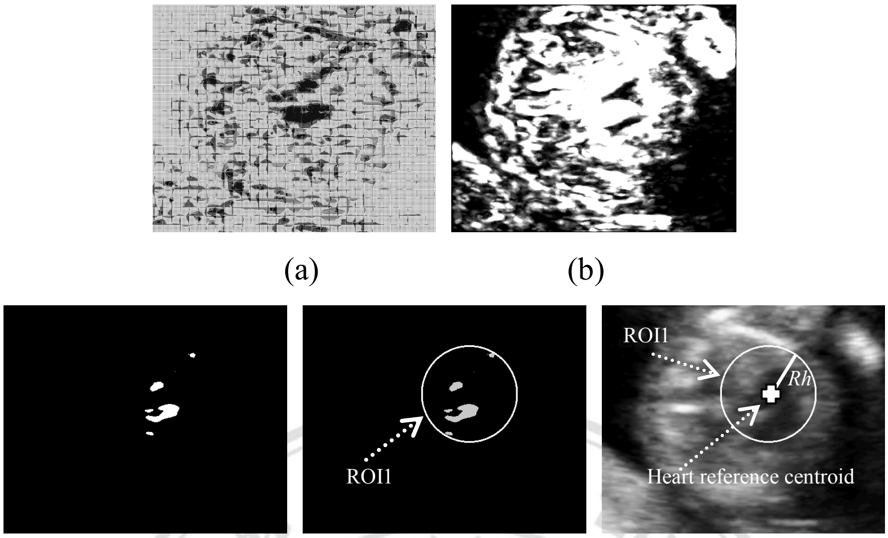
Since the fetus heart was in a circular shape, a circular ROI1 was used (figure 4.3(d)). The center of ROI1 was the centroid of the discovered objects called the heart reference centroid. The radius of ROI1 was the distance between the heart centroid and the farthest boundaries of the objects in the image. We called the radius of ROI1 as *Rh* (figure 4.3(e)). An example of ROI1 is shown in figure 4.3(e)

This information was used to find the position of ribs, select frames for PCM patch generation, find the heart structure, and so on.



(a) (b)

Figure 4.2 Original fetal heart ultrasound image (a) and the diagram shows the details in the image (b)



(a) (b)

(c) (d) (e)

Figure 4.3 Image of each step for finding heart reference position and ROI1, (a) example of magnitude velocity field, (b) additional result of all binarized magnitude velocity field images, (c) detected heart reference position, (d) ROI1 in a circular area and (e) ROI1 in ultrasound image background.

4.2 Ribs' Position Determination

In the four-chamber view of an ultrasound image, ribs were long, bright white areas, which were close to the heart as shown in figure 4.2. During the short time frame (1 second), the ribs positions were always in the same position. Hence, only the first frame was performed in this step.

The first frame was binarized by thresholding with threshold value obtained from 75% of maximum gray value. The longest object in the image with the distance (d_1) between the object centroid and the heart reference centroid less than $3 \times Rh$ was selected and classified as rib number one (Rib1). In the binary image (figure 4.4), the longest object whose the distance (d_1) between the object's centroid and the heart reference's centroid less than $3 \times Rh$ was indicated as rib number one (Rib1). Then, the rib on the other side of the body or Rib number two (Rib2) was assigned to the object which matched the following issues.

1. It was the longest object on the other side of Rib1 whose distance (d_2) between the object's centroid and the heart centroid were less than $3 \times Rh$.
2. The angle between d_1 and d_2 was greater than 90°.

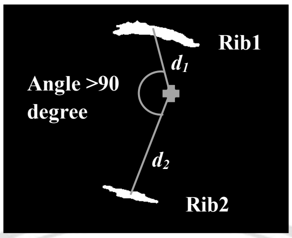


Figure 4.4 Rib1 and Rib2 of the same ultrasound image shown in figure 4.2(a)

4.3 Transverse Diameter (Td) Measurement

According to the fetal body, cross section is mostly in a circular shape so we drew a circle through the centroids of both ribs as shown in figure 4.5 (a). After that we found the center of the arc lines of the circle which overlaped both Rib1 and Rib2 (figure 4.5 (b)) and called as the rib center. Then the angle and center between both ribs was computed as shown in figure 4.5 (c). Next, rib was rotated to horizontal plane around the center. Finally, Td was the distance between the outermost of the left and right rib measured on the same plane of the line connecting the center of both ribs as shown in figure 4.5 (d).

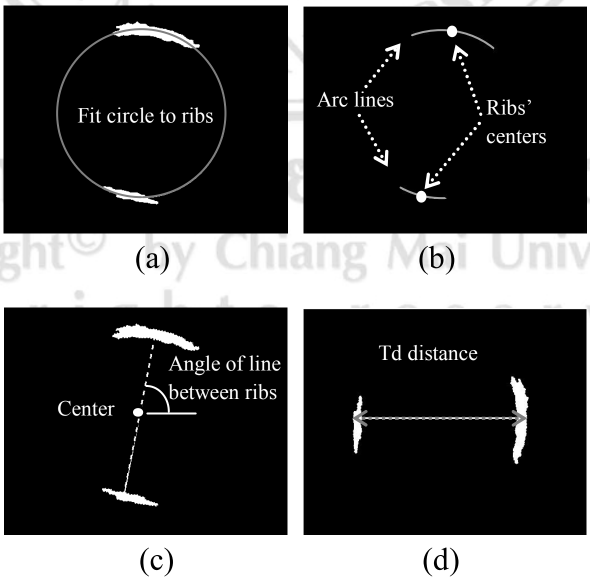


Figure 4.5 Method of Td measurements, (a) fitted circle to ribs, (b) determined arc lines and center of them, (c) found center and angle of line between center of the arc lines, (d) rotated line between center of arc lines to horizontal plane and measured Td.

4.4 Find Frames within End-diastolic and End-systolic Stage

The end-diastolic stage is suitable to measure heart sizes because the heart is fully expanded. From all frames in the first second of the ultrasound video (20-99 frames) there were only 2-3 frames which were in end-diastolic stage.

Firstly, the frames at end-diastolic (largest ventricle or widest Cd frame) [25] and end-systolic stages (smallest ventricle or smallest Cd frame) [25] were selected. Because within these stages, the heart had the least amount of movement as it slowed to stop before changing direction. The method to find frames in end-diastolic and end-systolic are as described in the following 3 steps:

1) Computing the average magnitude of velocity field (*A*) inside ROI1 of each frame as shown in figure 4.6. Then, the pairwise differences of *A* were computed by

$$D(i) = A(i+1) - A(i) \; for \; i = 1,\ldots,m-1 \tag{4.1}$$

where $D(i)$ is a pairwise difference of *A*.

$A(i)$ is the average velocity field of image frame *i*

m is the number of frames in the first second of ultrasound video

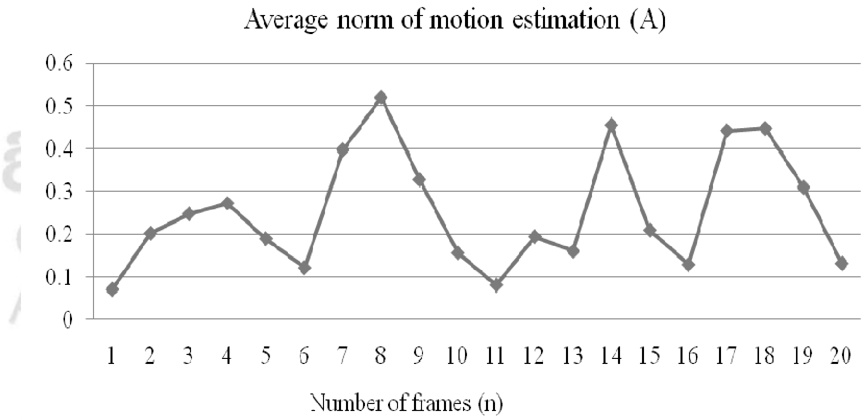


Figure 4.6 Graph of average magnitude velocity fields inside ROI1 of a 20 frames/second ultrasound video.

2) Then the reference frames for end-diastolic or end-systolic stage was selected. According to the maximum fetal heart rate is approximately 160

bpm or 3 bps and each beat contains both end-diastolic and end-systolic stages. Therefore, the maximum numbers of frames $(MaxFrame)$ that are in these two stages are equal to 6. We computed the minimum range of the reference frame (*Rs*) by

$$Rs = round\left(\frac{FrameRate}{MaxFrame}\right) - 1 \tag{4.2}$$

The algorithm for finding reference frames is as follow.

```
Let F be an array of selected frame number
Let k=1
If D(1)> 0 and A(i)<mean_A
    then F(k) =1, k=k+1     # select frame 1
For i=2, 3,…, m
    If D(i)>0 and F(k)−F(k−1)>Rs and A(i)<mean_A
        then F(k) =i, k=k+1       # select frame i
where mean_A was equal to average of A(i)
```

3) Then supposedly, the selected reference frame *i* is in the end-diastolic stage. The next stage in before and after this stage will be the end-systolic or vice versa. Let *j_after* and *j_before* be the frame numbers that are supposed to be in another stage after and before this stage, respectively. Then *j_after* and *j_before* are

$$j\_after = \text{round}\left(\frac{Rs}{2}\right) + 1 \tag{4.3}$$

$$j\_before = \text{round}\left(\frac{(Rs-1)}{3}\right) \tag{4.4}$$

Let *K* be the number of selected frames in step 3

Reference frames F(*k*), *k=1,2,….,K* were used for selecting end-diastolic and end-systolic stage frames F(*k*) with the lowest *A* in the specified range is selected using the follow algorithm.

Let $\hat{F}$ be an array of selected frames which will be improved from the selected reference frames.

Let l=1

For k=1,2,…,K

If k=1 then

$\hat{F}(l)$= select frame with the lowest value of A in [F(1),…,F(1+*j_after*)]

Else if $2 \le k \le K-1$ then

$\hat{F}(l)$= select frame with the lowest value of A in [F(k+*j_before*),

…,F(k),…,F(k+*j_after*]

Else $\hat{F}(l)$= Select frame with the lowest value of A in [F(*k-j_before*),

…,F(k)]

l=l+1

4.5 Heart Structure Segmentation

ROI2 was a circular shape which has the heart reference centroid as the center and the radius was the maximum distance between *d1* and *d2*. ROI2 supposedly covered the heart area. An example of the selected ROI2 is shown in figure 4.7(a).

Within ROI2, the selected frames were filtered by using a 5x5 median filter to smooth the image and eliminate noises and then clustered by patch-based PCM. In this experiment, PCM was used to generate 20 patches from 20 clusters. The patches were reordered in an ascending order according to their gray levels and assigned the new label ranging from 1 to 20 as shown in figure 4.7 (b).

Next, the similar patches of each selected frame were combined together into 2 regions, heart chambers and the background by following the methods below.

1) The lowest label of the patch inside ROI1 was determined. We called this label L. And, the number of patches that would be selected to combine as a heart chambers (N_p) was

$$N_p = round((20-L)*P)+L \quad (4.5)$$

where P is the percentage of the difference between gray levels of the heart chambers and the other areas. In the experiment, we set P=20%. For example, if L equals 5, then N_p will be 8.

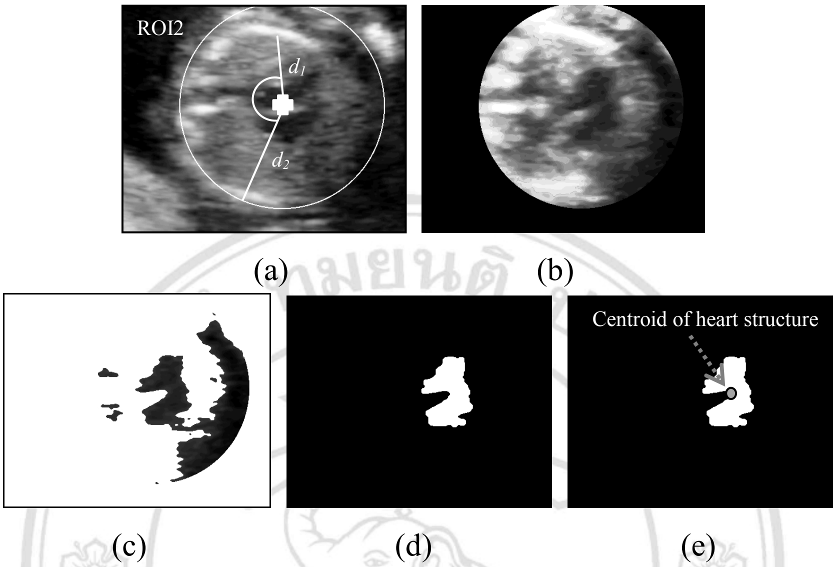


Figure 4.7 Images show steps of heart structure determination, (a) positions of d_1, d_2 and ROI2 on ultrasound image back ground, (b) gray color density clustered by PCM in ROI2, (c) image of noise around heart structure, (d) heart structure after removing noise, (e) centroid position of the heart structure.

2) The heart chamber was then segmented by combining all the patches with label 1 to N_p (figure 4.7(c)). For example, from the example in step 1, we would combine patches with prototypes of 1 to 8.

3) The small area of noises in the result in step2 was removed by opening operator with a disk structure element (SE) size of either 4×4, 6×6, or 8×8. The size of SE is selected base on size of ROI2. Let *hh* be (3/5) ×frame height and *rr* be 2×radius of ROI2. Then, we selected the SE size by using algorithm below.

```
If rr>hh then
    If rr>frame's height
        then SE's size is 8×8
    Else SE's size is 6×6
Else SE's size is 4×4
```

Then, we removed objects with the number of pixels less than the number of pixels inside the circle with radius > 0.1×ROI2.

4) Noise objects that connected to the boundary of ROI2 but did not overlap to ROI1 were removed.

5) After completing step1-4 of all selected frames the left over noises would be removed to get a heart structure (figure 4.7(d)) using the following criteria:

   5.1) When the objects found only in one image frame from all the selected frames.

   5.2) When the objects found only in one image frame from the selected even frames.

   5.3) When the objects found only in one image frame from the selected odd frames.

6) We increased *P* by 5% and repeated steps 1 to 5, if the maximum distance between the farthest point of the result object from step 5 was less than 40% (this was because normal heart size was approximately one third of the chest size [12] and since our ROI2 was bigger than the chest) of the radius of ROI2.

7) The centroid of each heart structure from all selected frames was computed. The centroid image is shown in figure 4.7(e).

4.6 Cardiac Diameter (Cd) Measurement

The cardiac diameter (Cd) is the length of the heart measured in perpendicular to interventricular septum (IVS). IVS is the wall that separates the lower heart chambers (ventricle) from one another. The process of finding IVS and Cd measurement is as follows:

1) Create a degree template as a circular shape image of recorded degree in each pixel and call it a degree template as shown in figure 4.8(a). The center of the template was a mean centroid of heart structure and the radius of the circular equaled to the radius of ROI2.

r = radius of ROI2,

$$(C_x, C_y) = (\sum_{b=1}^{n} \text{centroid of heart structure}_b) / n$$

where n = total number of selected frames

(C_x, C_y) is the coordinate of the mean centroid

For each pixel (i, j) in degree template (T)

$a(i, j) =$ angle of C and (i, j)

If distance between (i, j) and $(C_x, C_y) < r$ then

$T(i, j) = a(i, j)$

Else

$T(i, j) = 0$

End if

End for

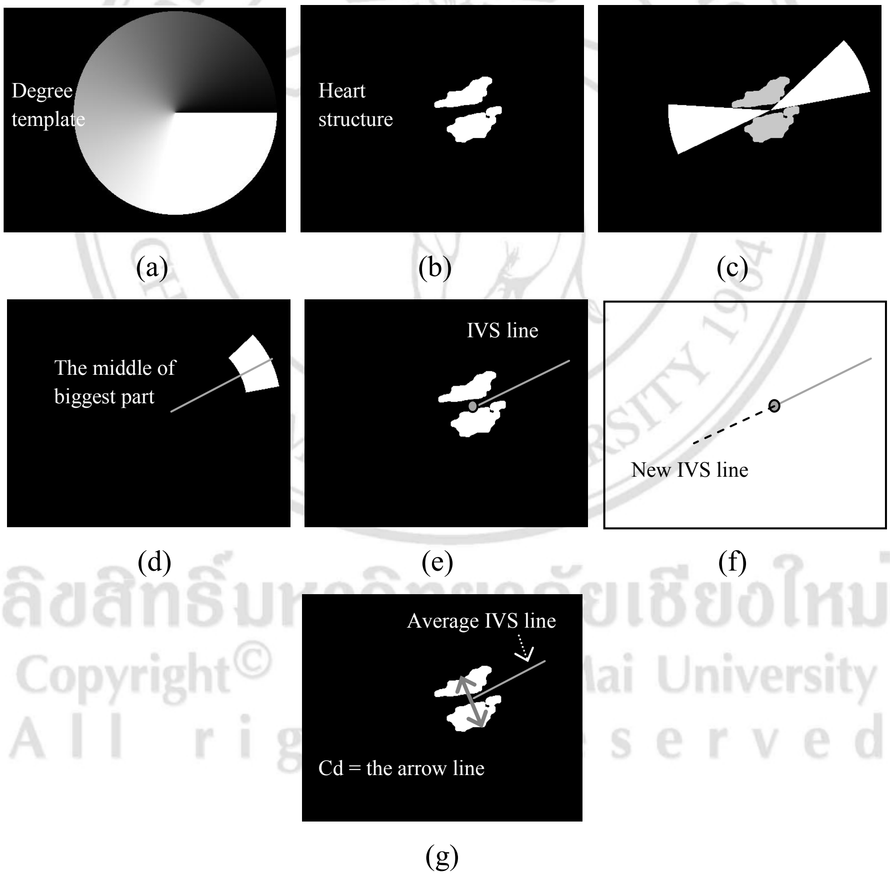


Figure 4.8 Method of finding average IVS line (a) image of degree template, (b) example of heart structure, (c) template angle which do not overlap to heart structure, (d) biggest part after cut around center and the middle angle, (e) IVS line of each heart structure, (f) adding IVS angle plus 180 degree, a new IVS line, (g) Cd length in arrow line.

2) Removed the pixels of each degree on degree template that overlapped to objects of heart structure (figure 4.8(b, c)) by the following algorithm.

$Hs =$ image of heart structure after remove noise

$Remove\_angle$ = a vector containting 1's with the size of 1-by-360

For each pixel in Hs

If $Hs(i,j)=1$ then

$Remove\_angle(T(i,j))=0$

End if

End for

$nonoverlap =$ an array of zero with the size of Hs

For $i=1,\ldots,360$

If $Remove\_angle(i)\neq 1$ then

All pixel location (k,j) in T that had degree equal to i would be used to locate the pixel position where $nonoverlap(k,j)=1$

End if

End for

3) Removed the non overlapped objects around center of degree template by the radius of $\left(\frac{1}{3}\right)\times$ radius of ROI2.

4) Selected the biggest area of the leftover object in order to find the middle angle, and then called it as an IVS line as shown in figure 4.8(d and e).

5) After the IVS lines of all selected frames were chosen, each selected IVS line was used to generate the new IVS line in the opposite direction as shown in figure 4.8(f).

6) Then, counted the numbers of the other IVS line that had less than 45 degree angle different from each IVS line. After that, determined the first IVS line with the highest number of close members. The mean of IVS angle of the member was calculated and get an average IVS line. The algorithm is shown below.

$n\_IVS =$ Total number of selected frames $\times 2$

$countgroup =$ a vector containng 0's with the size of 1-by-n_IVS

For $i = 1,...,n\_IVS$ then

$angle[i, j] = 0$

For $j = i+1,...,n\_IVS$ then

$angle[i, j] =$ angle between i *and* j

$angle[i, j] = angle[j, i]$

End for

For $p = 1,...,n\_IVS$ then

If $angle[i, p] < 45$ then

$countgroup[i] = countgroup[i] + 1$

End if

End for

End for

$nb =$ maximum value of *countgroup*

$line\_\max =$ index of maximum value of *countgroup*

$sum\_angle = 0$

For $i = 1,...,n\_IVS$

IF $angle[line\_\max, i] < 45$

$sum\_angle = sum\_angle +$ angle of line i

End if

End for

Average IVS line $= \dfrac{sum\_angle}{nb}$

7) Then, the widest distance of the object that is perpendicular to the average IVS line of each heart structure was computed as the heart diameter. Cd was equal to the longest distance and the frame with the longest distance was selected to be the biggest heart frame. The algorithm is shown below.

Let C = mean centroid of heart structure

For $i = 1, \ldots,$ number of selected frames

Draw line (i) that is perpendicular to average IVS line from C

$Length\_of\_line(i)$ = the widest length of object in line (i) direction

End for

Cd = $\max(Length\_of\_line)$