CHAPTER 5

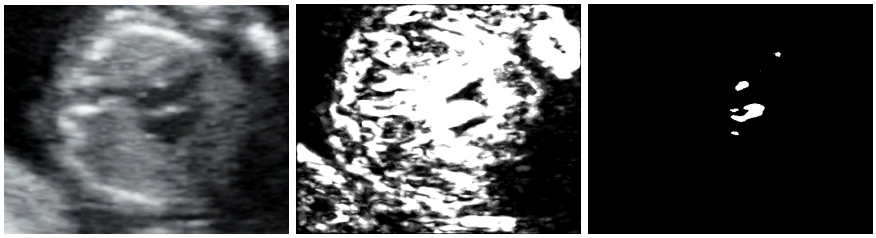
Results and Discussion

The proposed method is for detecting cardiomegaly on fetal heart ultrasound videos in four chamber view stage. For our research 99 ultrasound videos of the fetal hearts were used. They included videos of 34 normal and 65 abnormal cases provided by Professor Dr. Theera Tongsong, a medical doctor at Maharaj Nakorn Chiangmai Hospital. The results of our algorithm will be compared with the results of mentioned expert. On the other hand the result of 75 videos will be confirmed with another medical expert in the same hospital. To make it easy to understand, this chapter is going to report the results of our proposed method step by step as follows. Section 5.1 shows the result of the heart reference position, whereas section 5.2 shows ribs' position determination results. Section 5.3 provides transverse diameter (Td) measurement. Section 5.4 presents the results from frame selection within end-diastolic and end-systolic stage. Section 5.5 is the results concerning heart structure segmentation. In section 5.6, the results on the biggest heart frame selection is presented, followed by section 5.7 on cardiac diameter (Cd) measurement and section 5.8 on Cardiothoracic ratio (CT ratio) calculation. Finally section 5.9 provides the results of cardiomegaly diagnosis.

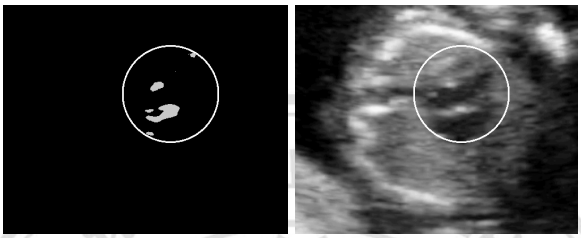
5.1 Result of Finding Heart Reference Position

An example of the original first frame is shown in figure 5.1(a). The summation result of all binarized magnitude velocity fields is in figure 5.1(b). Then, the summation result was binarized by Otsu's method to get the heart reference position as shown in figure 5.1(c). The ROI1 result is shown in figure 5.1(d and e).

By using our algorithm in section 4.1, we were able to detect some parts of the heart chamber area (the most movement area) which we could use it as a reference for finding rib and heart structure.



(a) (b) (c)



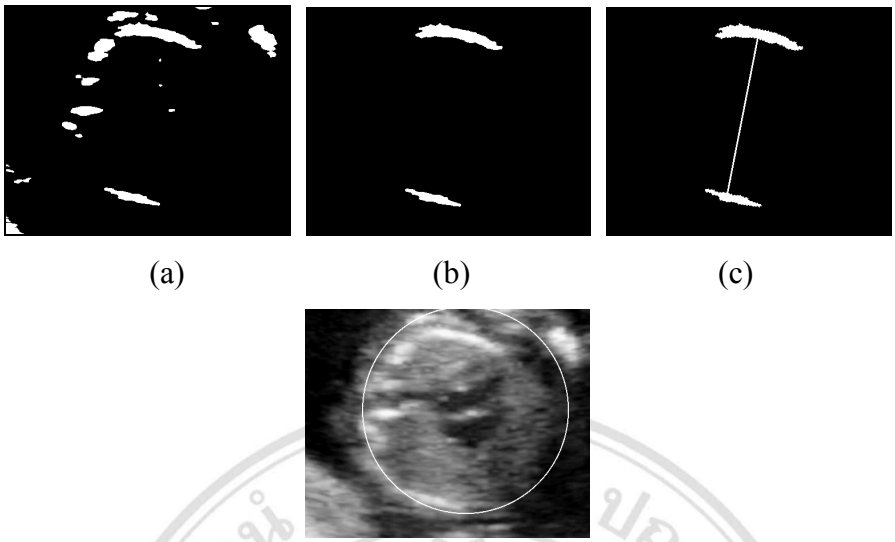
(d) (e)

Figure 5.1 Example result of finding heart reference position, (a) an original first frame, (b) addition result of all binarized magnitude velocity field images, (c) heart reference position, (d) ROI1 is an area inside the circle, (e) ROI1 on original image frame.

5.2 Result of Ribs' Position Determination

Since we assumed that the ribs position should be at the same position in every frame of the first second video, only the first frame was used to extract the rib position. After applying adaptive thresholding to the first frame following the method in section 4.2, the ribs candidates were emerged as shown in figure 5.2(a). By using the method in section 4.2, we obtained the rib position on both sides as shown in figure 5.2(b). Both detected ribs were used to find the Td position drawn by the line (figure 5.2(c)) by using the method in section 4.3. Also, the ribs position in figure 5.2(b) was used to identify the area inside the circle or ROI2 which indicated the whole heart (figure 5.2(d)).

Our algorithm could detect only some parts of ribs which affected on Td measurement. The error of rib determination and Td measurement will be discussed in the next section.



(a) (b) (c)

(d)

Figure 5.2 Example results of ribs' position determination, (a) objects left after threshold, (b) rib 1 and rib 2 positions, (c) Td position and (d) selected ROI2.

5.3 Result of Transverse Diameter (Td) Measurement

The Td percentage of errors are computed by

$$\% \text{ error } = \frac{\text{abs}\left(Td_{program} - Td_{expert}\right)}{Td_{expert}} \times 100 \tag{5.1}$$

The % error between expert opinions (75 videos) are compute by

$$\% \text{ difference opinion between experts } = \frac{\text{abs}\left(Td_{expert2} - Td_{expert1}\right)}{Td_{expert1}} \times 100 \tag{5.2}$$

The Td results of each patient were shown in table 5.1. The average, maximum, minimum, standard deviation of % error and % difference opinion between experts are in the table.

Table 5.1 Results of Transverse diameter (Td) compared with 2 experts.

Patient no.	Transverse diameter (Td)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
1	175	186	160	8.78	13.90	5.95
2	341	335	327	4.05	2.42	1.67
3	303	292	292	3.60	0.02	3.58

Table 5.1 Results of Transverse diameter (Td) compared with 2 experts.(continued)

Patient no.	Transverse diameter (Td)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
4	437	414	436	0.32	5.43	5.46
5	315	324	304	3.49	6.22	2.91
6	308	303	300	2.44	0.84	1.62
7	281	271	277	1.53	2.09	3.54
8	314	304	304	3.22	0.08	3.30
9	490	465	483	1.33	3.88	5.01
10	251	245	195	22.30	20.50	2.28
11	348	324	338	2.74	4.33	6.78
12	319	296	302	5.42	2.04	7.31
13	414	419	417	0.65	0.43	1.08
14	281	290	273	2.99	5.84	3.02
15	264	257	252	4.44	1.93	2.56
16	288	293	266	7.65	9.09	1.59
17	517	537	493	4.58	8.17	3.91
18	247	248	221	10.38	10.72	0.37
19	358	367	351	1.90	4.28	2.48
20	345	329	273	20.90	17.05	4.64
21	306	294	308	0.61	4.88	4.06
22	256	244	238	7.12	2.40	4.84
23	397	394	392	1.18	0.50	0.68
24	214	217	200	6.55	7.89	1.46
25	290	275	264	9.12	4.11	5.22
26	287	308	281	2.24	8.87	7.27
27	492	484	484	1.70	0.01	1.71
28	211	196	199	5.85	1.54	7.28
29	304	309	306	0.60	1.09	1.71
30	257	260	254	1.25	2.33	1.11
31	294	282	269	8.46	4.53	4.11
32	330	343	285	13.64	16.85	3.86
33	489	487	554	13.32	13.82	0.44
34	254	247	243	4.25	1.64	2.65
35	426	443	385	9.57	13.13	4.09

Table 5.1 Results of Transverse diameter (Td) compared with 2 experts.(continued)

Patient no.	Transverse diameter (Td)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
36	357	365	349	2.24	4.44	2.30
37	256	256	319	24.66	24.54	0.10
38	414	426	457	10.37	7.29	2.87
39	378	396	368	2.62	7.11	4.83
40	328	325	321	2.04	1.19	0.87
41	255	235	330	29.37	40.22	7.74
42	277	270	293	5.84	8.58	2.52
43	338	348	320	5.42	8.00	2.80
44	346	340	362	4.62	6.41	1.68
45	351	333	328	6.65	1.45	5.27
46	304	298	288	5.21	3.41	1.86
47	310	312	303	2.19	3.00	0.84
48	364	349	329	9.71	5.81	4.14
49	473	455	466	1.42	2.51	3.84
50	112	117	113	1.15	3.29	4.59
51	84	81	115	37.02	41.47	3.15
52	104	107	101	2.74	5.70	3.13
53	232	239	210	9.56	11.99	2.75
54	121	90	120	0.79	33.97	25.95
55	124	120	121	2.41	1.14	3.51
56	217	220	208	4.16	5.40	1.31
57	295	296	295	0.01	0.48	0.50
58	311	321	298	4.16	7.27	3.36
59	203	184	200	1.49	8.54	9.24
60	379	377	356	5.95	5.46	0.52
61	288	291	276	4.03	5.16	1.19
62	352	357	338	3.89	5.20	1.38
63	234	246	234	0.02	5.00	5.24
64	181	168	187	3.05	11.58	7.64
65	221	228	285	28.87	25.06	3.04
66	199	202	194	2.63	3.93	1.36
67	340	340	329	3.12	3.26	0.14
68	235	253	224	4.58	11.46	7.77

Table 5.1 Results of Transverse diameter (Td) compared with 2 experts.(continued)

Patient no.	Transverse diameter (Td)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
69	276	274	282	2.14	2.76	0.60
70	290	285	293	0.87	2.86	1.94
71	239	221	242	1.21	9.44	7.52
72	162	166	175	8.13	5.51	2.48
73	335	298	329	1.76	10.35	10.98
74	181	186	168	7.10	9.55	2.71
75	351	357	340	3.19	4.78	1.66
76	233	N/A	199	14.68	N/A	N/A
77	184	N/A	184	0.06	N/A	N/A
78	250	N/A	234	6.22	N/A	N/A
79	314	N/A	317	1.08	N/A	N/A
80	279	N/A	260	6.90	N/A	N/A
81	365	N/A	363	0.52	N/A	N/A
82	310	N/A	222	28.30	N/A	N/A
83	304	N/A	272	10.56	N/A	N/A
84	223	N/A	224	0.26	N/A	N/A
85	281	N/A	279	0.64	N/A	N/A
86	449	N/A	325	27.57	N/A	N/A
87	310	N/A	314	1.29	N/A	N/A
88	188	N/A	187	0.52	N/A	N/A
89	235	N/A	233	0.78	N/A	N/A
90	239	N/A	217	9.33	N/A	N/A
91	227	N/A	218	3.99	N/A	N/A
92	305	N/A	310	1.64	N/A	N/A
93	168	N/A	169	0.44	N/A	N/A
94	502	N/A	496	1.21	N/A	N/A
95	465	N/A	426	8.30	N/A	N/A
96	277	N/A	244	12.07	N/A	N/A
97	287	N/A	280	2.28	N/A	N/A
98	396	N/A	341	13.89	N/A	N/A
99	202	N/A	197	2.44	N/A	N/A
Average				6.16	7.57	3.67
Maximum				37.02	41.47	25.95
Minimum				0.01	0.01	0.10
Standard deviation				7.35	8.30	3.50

The average Td error percentage compared to result of expert number 1 from 99 videos and 2 from 75 videos were 6.16% and 7.57%, respectively. The average of different opinion between experts from 75 videos is 3.67%. The fluctuation of the Td error percentage could be happened.

The Td errors below 10% may possibly occur due to our proposed methodology 4.2 used in our experiment provides the incomplete rib shape causing false Td position as shown in figure 5.3. In figure 5.3, (a) shows the original ultrasound image and the true ribs position in the circle, while (b and c) show the results of adaptive threshold and ribs position determined by the method in section 4.2. The incomplete ribs shape affected different direction for measuring Td (figure 5.3(e)) when compared with the direction from expert in figure 5.3(f). The ribs became thinner after applying threshold. As a result, Td value also became slightly less than the expert measurement's.

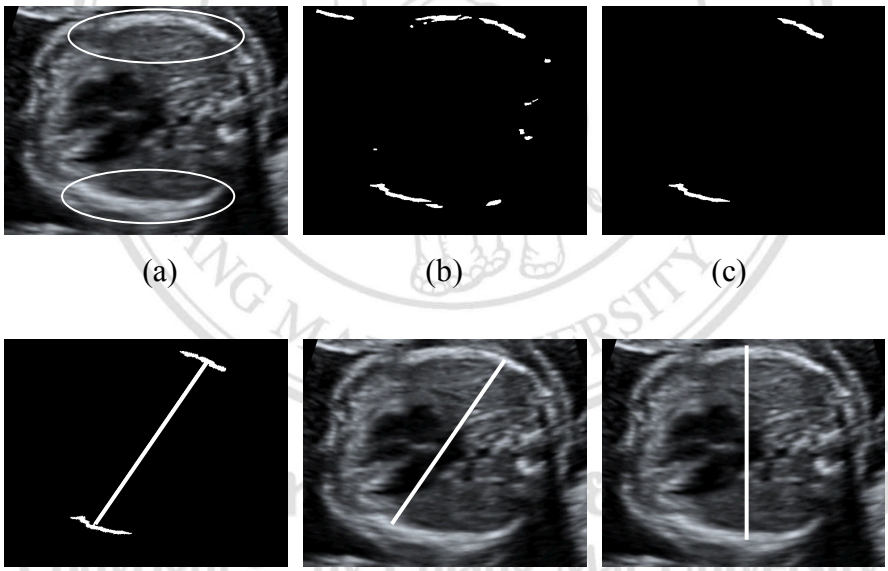


Figure 5.3 Td error from video number 44, (a) original ultrasound image and rib position, (b) the result of adaptive threshold following method from section 4.2, (c) the incomplete ribs selected by the program, (d) wrong Td position on incomplete ribs, (e) wrong Td position on ultrasound image and (f) Td position from expert.

For the Td errors over 10% could occur from wrong objects measurement because few original ultrasounds had incomplete rib images affecting miss selection by our program. Figure 5.4 (a) is the original ultrasound image which shows an incomplete rib. The ribs should be seen in dot circles in figure 5.4(a). The algorithm in section 4.2 selected a wrong object as a ribs position as shown in figure 5.4 (b and c). The false Td position and the corrected Td position from expert is in figure 5.4 (e and f), respectively.

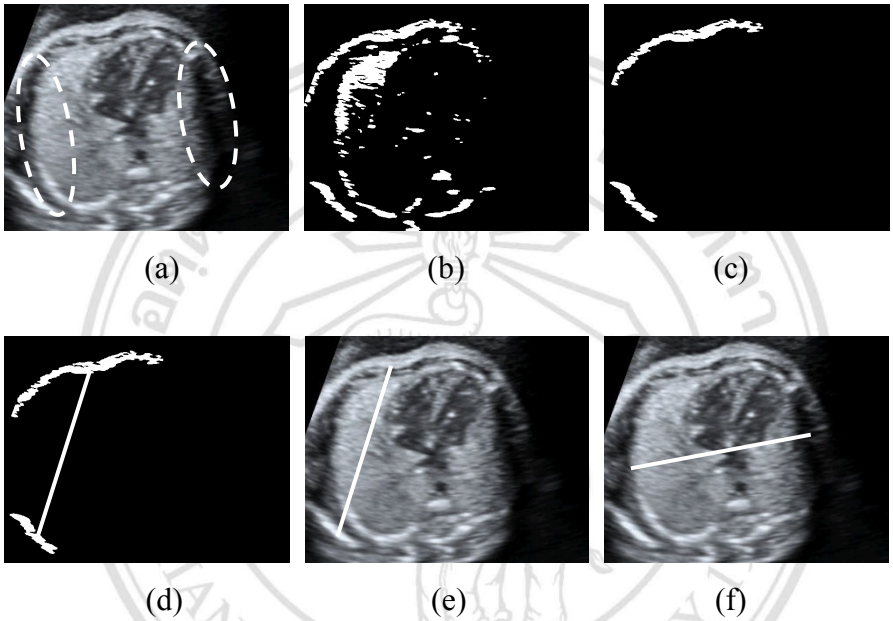
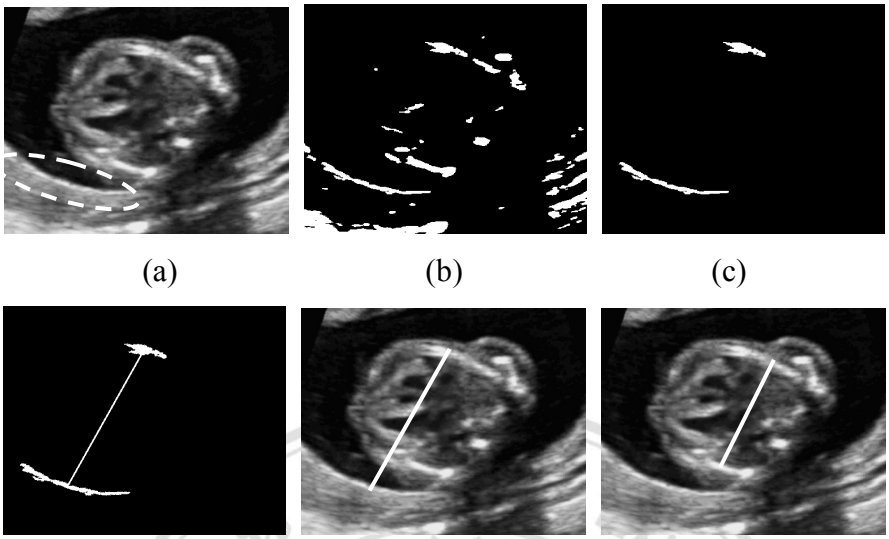


Figure 5.4 Td error from video number 98, (a) original ultrasound image, (b) result of adaptive threshold following method from section 4.2, (c) program selected other object as ribs, (d) Td position from wrong ribs, (e) wrong Td position on ultrasound image and (f) Td position from expert.

The other problem is the appearance of other long and bright objects (in the dashed circle in figure 5.5(a)) which is close to the rib. Therefore, false rib selection (Figure 5.5 (c)) by the program was happened. The Td results of our algorithm and expert are shown in figure 5.5 (e and f), respectively.



(a) (b) (c)

(d) (e) (f)

Figure 5.5 Td error from video number 65, (a) original ultrasound image, (b) result of adaptive threshold following method from section 4.2, (c) program selected other object as ribs, (d) Td position from wrong ribs, (e) wrong Td position on ultrasound image and (f) Td position from expert.

5.4 Result of Frames Selection within End-diastolic and End-systolic Stage

Since the heart has the least amount of movement as it slows to stop in end-diastolic and end-systolic before changing direction, we use the information of motion estimation in ROI1(heart reference position) to indicate the frame number in end-diastolic and end-systolic stage within the first second (20-99 frames). With this method, we can reduce a lot of frames before applying heart structure segmentation in the next step.

The results of selected frames in end-diastolic and end-systolic are shown in table 5.2. Our proposed method is acceptable when the expert choose one of the frames selected by the program.

By the expert opinion, the frames selected by the program is unacceptable if more than 3 frames difference from the expert. Frame rate of all videos are in the range of 20-99 frames/second. At the lowest frame rate (20 frames/second) 3 frames difference may very much change heart structure. For example, in table 5.3, the selected frames of patient number 3, 8 and 54 are acceptable by expert. However, patient number 26 is unacceptable because there are more than 3 frames difference from the expert. The

program selected the slowest movement frames while clear heart chamber and the biggest heart frames (end-diastolic stage) were selected by the experts. The frame rate of the video of patient number 26 is 99 frame /sec. It is the highest frame rate. Therefore in patient number 26, the difference of 6 frames from expert is still not much change of heart structure.

Table 5.2 Result of selected frames in end-diastolic and end-systolic stages.

Patient no.	Frame number selected by our proposed method (within end-diastolic and end-systolic stages)						Expert selected	Judgment
1	9	29	44	62	79	-	44	Acceptable
2	1	21	36	52	-	-	36	Acceptable
3	8	27	48	68	-	-	50	Acceptable
4	9	18	30	39	54	-	30	Acceptable
5	3	6	10	-	-	-	10	Acceptable
6	3	9	16	22	-	-	22	Acceptable
7	10	23	36	49	-	-	23	Acceptable
8	1	14	28	43	55	-	30	Acceptable
9	2	15	28	42	57	-	2	Acceptable
10	1	6	13	19	27	-	6	Acceptable
11	2	21	35	51	67	-	2	Acceptable
12	2	10	16	26	36	41	41	Acceptable
13	5	21	38	54	-	-	5	Acceptable
14	1	14	26	41	53	65	26	Acceptable
15	8	16	26	38	46	-	8	Acceptable
16	10	21	36	50	66	-	21	Acceptable
17	1	14	28	41	54	65	54	Acceptable
18	4	11	18	31	-	-	4	Acceptable
19	4	15	26	34	-	-	26	Acceptable
20	6	39	49	71	-	-	6	Acceptable
21	4	14	24	31	39	-	4	Acceptable
22	5	17	35	49	66	-	49	Acceptable
23	7	29	46	-	-	-	7	Acceptable
24	3	17	28	41	54	-	3	Acceptable
25	11	35	51	68	-	-	51	Acceptable
26	6	21	41	59	79	-	65	Unacceptable
27	7	20	38	59	-	-	7	Acceptable

Table 5.2 Result of selected frames in end-diastolic and end-systolic stages. (continued)

Patient no.	Frame number selected by our proposed method (within end-diastolic and end-systolic stages)						Expert selected	Judgment
28	2	11	29	48	61	-	2	Acceptable
29	1	15	26	34	44	-	26	Acceptable
30	3	7	11	20	-	-	3	Acceptable
31	1	17	37	56	76	-	17	Acceptable
32	8	18	30	41	51	-	41	Acceptable
33	1	10	24	38	46	-	1	Acceptable
34	1	27	44	68	84	-	27	Acceptable
35	3	20	33	46	-	-	33	Acceptable
36	2	15	26	44	53	-	44	Acceptable
37	9	23	36	51	63	-	63	Acceptable
38	8	24	40	50	-	-	8	Acceptable
39	6	18	30	41	51	-	18	Acceptable
40	1	14	25	39	51	-	25	Acceptable
41	2	9	14	20	28	33	14	Acceptable
42	1	10	15	20	26	-	15	Acceptable
43	9	20	32	44	-	-	32	Acceptable
44	16	30	49	63	-	-	30	Acceptable
45	8	30	45	66	82	-	45	Acceptable
46	5	18	36	54	70	-	54	Acceptable
47	1	17	31	47	59	-	59	Acceptable
48	16	31	52	64	-	-	31	Acceptable
49	1	14	30	41	57	-	14	Acceptable
50	4	8	16	19	-	-	8	Acceptable
51	3	9	14	19	-	-	14	Acceptable
52	1	4	10	14	20	-	4	Acceptable
53	3	9	16	20	-	-	20	Acceptable
54	1	6	11	16	20	-	7	Acceptable
55	4	9	14	20	-	-	15	Acceptable
56	1	10	20	29	40	-	10	Acceptable
57	2	11	21	33	44	-	44	Acceptable
58	1	14	25	35	46	-	35	Acceptable
59	2	15	28	49	58	71	2	Acceptable
60	1	8	17	26	35	46	1	Acceptable
61	2	11	18	30	37	47	2	Acceptable

Table 5.2 Result of selected frames in end-diastolic and end-systolic stages. (continued)

Patient no.	Frame number selected by our proposed method (within end-diastolic and end-systolic stages)						Expert selected	Judgment
62	1	8	20	28	36	49	8	Acceptable
63	2	15	23	34	42	50	15	Acceptable
64	5	19	28	38	50	-	5	Acceptable
65	1	11	21	32	40	-	1	Acceptable
66	9	19	27	38	-	-	9	Acceptable
67	3	15	22	35	42	-	22	Acceptable
68	1	8	17	26	35	46	1	Acceptable
69	1	13	23	35	47	-	1	Acceptable
70	5	15	25	36	45	-	36	Acceptable
71	8	17	28	37	46	-	17	Acceptable
72	3	12	29	37	47	-	37	Acceptable
73	8	19	29	37	-	-	19	Acceptable
74	9	21	27	49	-	-	49	Acceptable
75	6	12	19	31	44	-	19	Acceptable
76	5	30	44	70	86	-	5	Acceptable
77	1	25	47	62	84	-	25	Acceptable
78	7	27	46	69	85	-	7	Acceptable
79	8	29	47	67	87	-	87	Acceptable
80	13	32	49	65	87	-	49	Acceptable
81	11	27	42	63	-	-	11	Acceptable
82	20	44	68	86	-	-	86	Acceptable
83	2	23	43	64	85	-	85	Acceptable
84	5	9	16	22	30	-	9	Acceptable
85	6	14	33	39	54	-	6	Acceptable
86	8	37	53	85	-	-	37	Acceptable
87	7	25	43	61	79	-	43	Acceptable
88	5	23	41	59	78	-	59	Acceptable
89	6	17	35	46	64	75	75	Acceptable
90	1	16	33	47	62	-	47	Acceptable
91	13	33	46	65	-	-	13	Acceptable
92	7	13	25	33	-	-	13	Acceptable
93	8	38	52	80	-	-	8	Acceptable
94	2	15	32	49	63	-	15	Acceptable
95	10	21	32	48	54	-	54	Acceptable

Table 5.2 Result of selected frames in end-diastolic and end-systolic stages. (continued)

Patient no.	Frame number selected by our proposed method (within end-diastolic and end-systolic stages)						Expert selected	Judgment
96	1	17	34	53	72	-	17	Acceptable
97	2	16	36	52	70	-	36	Acceptable
98	5	15	28	38	-	-	5	Acceptable
99	5	19	28	40	50	-	50	Acceptable

From the total selected 472 frames from 99 videos used in the experiment, the accuracy of our proposed methodology is 98.94%.

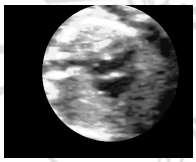
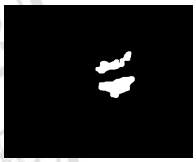
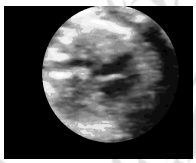
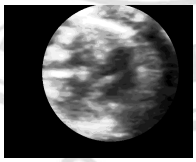
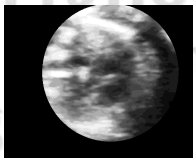
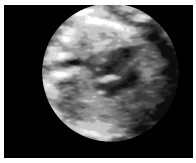
Table 5.3 Example of end-diastolic frames differently selected by our proposed method compare with expert's selected frames.

Patient no.	Program	Expert	Decision
3			Acceptable
	Frame number 48	Frame number 50	
8			Acceptable
	Frame number 28	Frame number 30	
26			Un acceptable
	Frame number 59	Frame number 65	
54			Acceptable
	Frame number 6	Frame number 7	

5.5 Result of Heart Structure Segmentation

The selected frames were clustered by PCM inside ROI2 to generate 20 patches. Then, the patches were combined as mentioned in section 4.5 and removed noises to get the heart structure. Examples are shown in table 5.4.

Table5.4 Example result of heart structure determination on the selected frames within end-diastolic and end-systolic stages.

No. of frames selected	Original image of selected frames	PCM patch generation	Combine low gray level value patches	Heart structure after remove noise
1				
15				
26				
34				
44				

To evaluate the segmentation performance of our proposed method we compared the result with expert number 1. Example of segmented fetal heart structure in the biggest heart frame from our proposed method and expert are shown in figure 5.6 (a, b). The segmentation error (Eseg) is calculated by

$$\text{Eseg} = \frac{(J_1 + J_2)}{\text{Total number of pixels in the image}} \times 100 \tag{5.3}$$

where J_1 is the number of pixels of heart structure from expert segmentation but our proposed method assigns them to non-heart structure.

J_2 is the number of pixels of non-heart structure from expert segmentation but our proposed method assigns them to heart structure.

(a) (b)

(c) (d)

Figure 5.6 Example of heart structure segmentation result in the biggest heart frame compare with expert, (a) expert segmentation result, (b) our proposed method segmentation result, (c) non-heart structure from expert segmentation but our proposed method assigns them to heart structure, (d) heart structure from expert segmentation but our proposed method assigns them to non-heart structure.

The segmentation error of each patient is shown in table 5.5. The average, maximum, minimum, and standard deviation of Eseg between experts are in the table.

Table 5.5 Segmentation error (Eseg)

Patient no.	Segmentation error			
	J_1*	J_2**	Total number of pixel	Eseg (%)
1	572	547	81920	1.37
2	2616	2823	200000	2.72
3	6955	669	200000	3.81
4	15078	4767	392000	5.06
5	9647	0	200000	4.82
6	3806	134	200000	1.97
7	4606	2786	162000	4.56
8	8878	3	200000	4.44
9	8508	949	392000	2.41
10	8713	67	128000	6.86
11	16778	0	200000	8.39
12	9284	251	200000	4.77
13	11003	484	392000	2.93
14	10231	2010	200000	6.12
15	6600	6	128000	5.16
16	7859	774	128000	6.74
17	22683	0	392000	5.79
18	7432	1250	128000	6.78
19	11884	5791	288000	6.14
20	7740	20	288000	2.69
21	5541	64	162000	3.46
22	6705	662	128000	5.76
23	10491	771	242000	4.65
24	5108	0	103680	4.93
25	5656	4	128000	4.42
26	2400	460	162000	1.77
27	28938	1490	392000	7.76
28	4756	230	103680	4.81
29	2292	422	200000	1.36
30	12970	2579	200000	7.77
31	5460	1264	200000	3.36
32	12119	374	200000	6.25
33	19227	4209	468180	5.01

Table 5.5 Segmentation error (Eseg)(continued)

Patient no.	Segmentation error			
	J_1*	J_2**	Total number of pixel	Eseg (%)
34	5672	1183	200000	3.43
35	16168	6634	392000	5.82
36	11933	2124	392000	3.59
37	4195	673	200000	2.43
38	6303	392	288000	2.32
39	18880	3740	288000	7.85
40	5696	5749	242000	4.73
41	4571	6500	200000	5.54
42	6005	221	200000	3.11
43	5222	719	200000	2.97
44	14684	0	200000	7.34
45	7998	247	200000	4.12
46	7855	1682	200000	4.77
47	2592	2415	200000	2.50
48	12776	152	200000	6.46
49	25452	4580	392000	7.66
50	1529	771	83200	2.76
51	651	4727	83200	6.46
52	976	9	83200	1.18
53	3378	492	83200	4.65
54	747	94	83200	1.01
55	923	10	83200	1.12
56	5010	307	200000	2.66
57	7855	15	200000	3.94
58	7267	4010	200000	5.64
59	5897	931	128000	5.33
60	4052	383	200000	2.22
61	7108	242	200000	3.68
62	6687	1515	200000	4.10
63	4036	60	128000	3.20
64	2943	619	72000	4.95
65	2835	1817	200000	2.33
66	4205	439	200000	2.32
67	7506	24	200000	3.77

Table 5.5 Segmentation error (Eseg)(continued)

Patient no.	Segmentation error			
	J_1*	J_2**	Total number of pixel	Eseg (%)
68	1555	155	200000	0.86
69	3028	5667	200000	4.35
70	4133	12555	162000	10.30
71	3418	1176	162000	2.84
72	1171	2211	81920	4.13
73	9067	149	162000	5.69
74	3355	1402	72000	6.61
75	3303	793	200000	2.05
76	3762	6010	128000	7.63
77	1548	755	81920	2.81
78	3690	56	128000	2.93
79	4007	1699	162000	3.52
80	4730	2748	162000	4.62
81	7379	12650	200000	10.01
82	8949	318	200000	4.63
83	8995	255	200000	4.63
84	3481	2080	128000	4.34
85	8839	2646	162000	7.09
86	8712	1022	288000	3.38
87	5359	229	200000	2.79
88	2180	309	81920	3.04
89	5293	474	81920	7.04
90	3450	15	128000	2.71
91	3815	2927	128000	5.27
92	8327	2462	200000	5.39
93	2583	57	72000	3.67
94	7784	16846	392000	6.28
95	15752	3186	392000	4.83
96	3992	1022	128000	3.92
97	5522	2047	200000	3.78
98	12946	2820	288000	5.47
99	3985	754	128000	3.70
Average				4.46
Maximum				10.30
Minimum				0.86
Standard deviation				1.95

* J_1 is the number of pixel of heart structure from expert segmentation but our proposed method assigns them to non-heart structure.

** J_2 is the number of pixel of non-heart structure from expert segmentation but our proposed method assigns them to heart structure.

The average result of Eseg in all 99 videos is 4.46%. In the process of removing noise by opening operation made heart structure became smaller than expert. Therefore, pixel number in J_1 is increased and pixel number in J_2 might be reduced as shown in figure 5.6(c). On the other hand, the segmentation error could occur in some ultrasound images due to an appearance of the low gray level area (dark area in the dashed circle in figure 5.7 (a)) close/connect to heart chamber. Our algorithm was unable to remove it or selected it as a heart structure and caused high pixel value in J_2 as shown in figure 5.7(d).

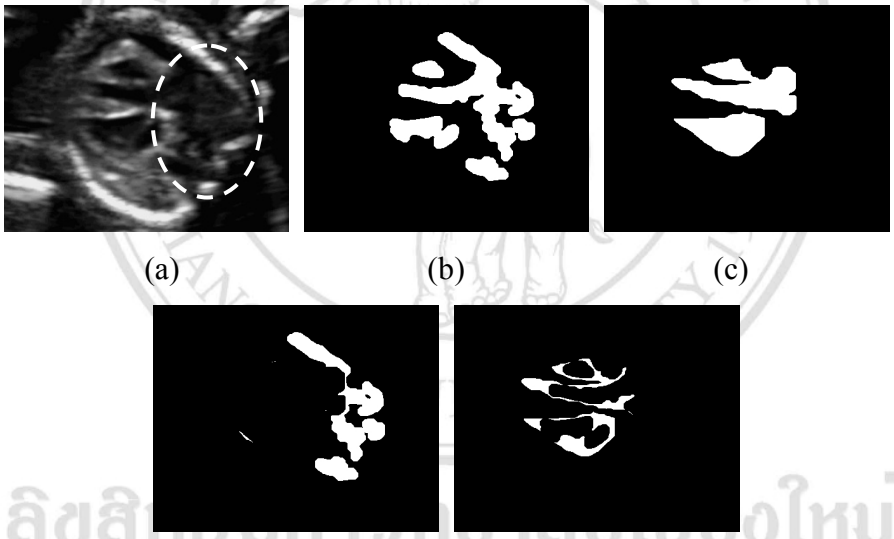


Figure 5.7 Example of error of heart structure segmentation from video number 70, (a) original ultrasound image, (b) our proposed method segmentation result, (c) expert segmentation result, (d) non-heart structure from expert segmentation but our proposed method assigns them to heart structure, (e) heart structure from expert segmentation but our proposed method assigns them to non-heart structure

5.6 Result of the Biggest Heart Frame Selection

In the result our proposed algorithm selected 44 frames from 99 videos similar to the selection of expert number 1. On the other hand our algorithm selected 26 frames from 75 videos similar to the selection of expert number 2. The different opinion between experts from 75 videos were 18 cases which equaled to 24 % as shown in table 5.6.

Table 5.6 Result of the biggest heart frame number selection compared with 2 experts.

Patient no.	Frame of biggest heart			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Same = O, Difference =X	Same = O, Difference =X	Correct = O, Incorrect= X
1	44	9	44	O	X	X
2	36	36	36	O	O	O
3	50	50	68	X	X	O
4	30	30	30	O	O	O
5	10	10	10	O	O	O
6	22	22	22	O	O	O
7	23	23	23	O	O	O
8	30	23	55	X	X	X
9	2	2	42	X	X	O
10	6	19	13	X	X	X
11	2	2	2	O	O	O
12	41	43	16	X	X	X
13	5	5	5	O	O	O
14	26	53	26	O	X	X
15	8	8	26	X	X	O
16	21	21	66	X	X	O
17	54	54	54	O	O	O
18	4	4	31	X	X	O
19	26	26	4	X	X	O
20	6	49	6	O	X	X
21	4	4	4	O	O	O
22	49	49	35	X	X	O
23	7	7	7	O	O	O
24	3	3	28	X	X	O

Table 5.6 Result of the biggest heart frame number selection compared with 2 experts. (continued)

Patient no.	Frame of biggest heart			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Same = O, Difference =X	Same = O, Difference =X	Correct = O, Incorrect= X
25	51	51	51	O	O	O
26	65	65	6	X	X	O
27	7	7	20	X	X	O
28	2	2	11	X	X	O
29	26	26	26	O	O	O
30	3	3	20	X	X	O
31	17	17	1	X	X	O
32	41	41	18	X	X	O
33	1	1	1	O	O	O
34	27	68	84	X	X	X
35	33	33	33	O	O	O
36	44	44	53	X	X	O
37	63	63	9	X	X	O
38	8	40	8	O	X	X
39	18	18	51	X	X	O
40	25	25	1	X	X	O
41	14	33	14	O	X	X
42	15	15	15	O	O	O
43	32	9	32	O	X	X
44	30	30	30	O	O	O
45	45	45	66	X	X	O
46	54	54	70	X	X	O
47	59	59	59	O	O	O
48	31	64	31	O	X	X
49	14	41	1	X	X	X
50	8	8	4	X	X	O
51	14	14	14	O	O	O
52	4	4	4	O	O	O
53	20	20	16	X	X	O

Table 5.6 Result of the biggest heart frame number selection compared with 2 experts. (continued)

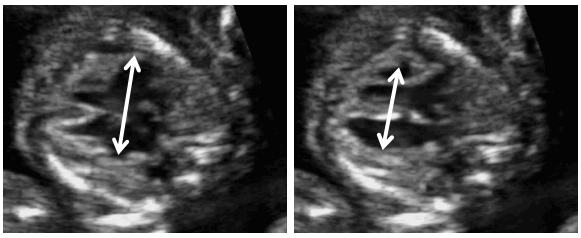
Patient no.	Frame of biggest heart			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Same = O, Difference =X	Same = O, Difference =X	Correct = O, Incorrect= X
54	7	16	1	X	X	X
55	15	15	20	X	X	O
56	10	10	20	X	X	O
57	44	44	44	O	O	O
58	35	35	46	X	X	O
59	2	58	49	X	X	X
60	1	35	1	O	X	X
61	2	2	37	X	X	O
62	8	8	20	X	X	O
63	15	34	15	O	X	X
64	5	5	5	O	O	O
65	1	1	1	O	O	O
66	9	9	19	X	X	O
67	22	22	22	O	O	O
68	1	1	1	O	O	O
69	1	1	47	X	X	O
70	36	36	36	O	O	O
71	17	37	17	O	X	X
72	37	37	37	O	O	O
73	19	37	19	O	X	X
74	49	49	9	X	X	O
75	19	19	6	X	X	O
76	5	N/A	86	X	N/A	N/A
77	25	N/A	25	O	N/A	N/A
78	7	N/A	46	X	N/A	N/A
79	87	N/A	87	O	N/A	N/A
80	49	N/A	65	X	N/A	N/A
81	11	N/A	11	O	N/A	N/A
82	86	N/A	68	X	N/A	N/A
83	85	N/A	85	O	N/A	N/A
84	9	N/A	5	X	N/A	N/A

Table 5.6 Result of the biggest heart frame number selection compared with 2 experts. (continued)

Patient no.	Frame of biggest heart			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Same = O, Difference =X	Same = O, Difference =X	Correct = O, Incorrect= X
85	6	N/A	14	X	N/A	N/A
86	37	N/A	85	X	N/A	N/A
87	43	N/A	7	X	N/A	N/A
88	59	N/A	59	O	N/A	N/A
89	75	N/A	64	X	N/A	N/A
90	47	N/A	47	O	N/A	N/A
91	13	N/A	33	X	N/A	N/A
92	13	N/A	25	X	N/A	N/A
93	8	N/A	80	X	N/A	N/A
94	15	N/A	15	O	N/A	N/A
95	54	N/A	48	X	N/A	N/A
96	17	N/A	72	X	N/A	N/A
97	36	N/A	16	X	N/A	N/A
98	5	N/A	38	X	N/A	N/A
99	50	N/A	19	X	N/A	N/A
Number of the same selected biggest heart frames				44	26	57
Number of different selected biggest heart frames				55	49	18

Basically, experts make the decision based on the biggest ventricle size emerging at the end-diastolic stage while our program instead performs the biggest heart frame (biggest heart structure) selection. The program perhaps reveals the bigger atrium than ventricle in end-systolic stage. It affects on Cd measurement as shown in figure 5.8.

The difference of frame selection by experts has less effect on Cd measurement because they both selected at the end-diastolic stage.



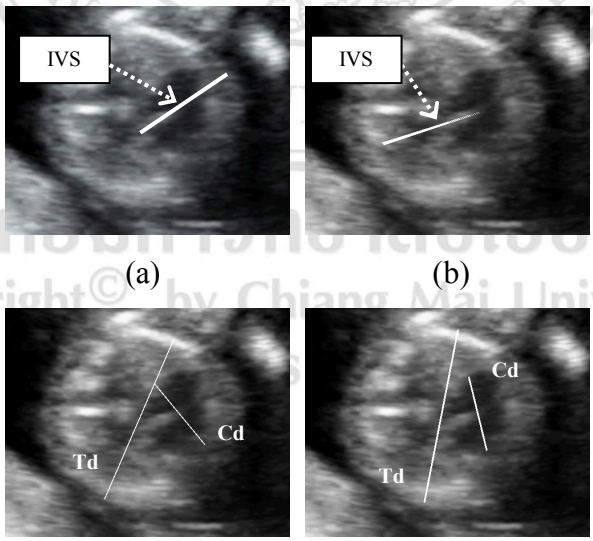
(a) (b)

Figure 5.8 Example of bigger atrium at end-systolic stage than ventricle at end-diastolic stage of patient number 58, (a) size of atrium in frame number 46 at end-systolic stage, (b) size of ventricle in frame number 35 at end-diastolic stage.

5.7 Result of Cardiac Diameter (Cd) measurement

To find cardiac diameter (Cd), IVS position needed to be located. The results of IVS position indicated by our proposed method and expert are shown in figure 5.9 (a and b). Results of Cd and Td on original ultrasound images from expert and our proposed method are shown in figure 5.9 (c and d). The error percentage of Cd was computed by

$$\% \text{ error} = \frac{\text{abs}\left(Cd_{program} - Cd_{expert}\right)}{Cd_{expert}} \times 100 \tag{5.4}$$



(a) (b)

(c) (d)

Figure 5.9 Example of position of IVS, Cd and Td on original image (a) IVS positioned by expert, (b) IVS position indicated by proposed method, (c) Td and Cd positions indicated by expert, (d) Td and Cd positions indicated by proposed method.

The % error between experts opinions are compute by

$$\%\ \text{difference opinion between experts} = \frac{\text{abs}\left(Cd_{expert2} - Cd_{expert1}\right)}{Cd_{expert1}} \times 100 \qquad (5.5)$$

The Cd average error percentage of each patient is shown in table 5.6. The average, maximum, minimum, and standard deviation are in the table.

Table 5.7 Result of cardiac diameter of our proposed method compared with 2 experts.

Patient no.	Cardiac diameter (Cd)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
1	67	58	52	22.12	9.83	13.63
2	179	179	163	8.94	8.75	0.21
3	188	186	190	0.88	2.38	1.47
4	252	248	207	17.76	16.57	1.43
5	150	131	103	31.34	21.64	12.37
6	171	153	139	18.53	9.12	10.36
7	157	154	165	4.98	7.14	2.02
8	153	169	131	14.10	22.42	10.71
9	260	258	209	19.67	19.09	0.72
10	178	175	146	18.05	16.57	1.78
11	190	187	143	24.92	23.56	1.79
12	178	162	141	20.66	12.98	8.82
13	201	215	187	7.07	13.22	7.09
14	189	180	159	15.79	11.72	4.62
15	146	142	133	8.95	6.07	3.06
16	140	122	138	1.50	12.88	12.74
17	295	280	252	14.69	10.04	5.16
18	155	165	145	6.48	12.22	6.53
19	259	266	321	24.15	20.72	2.84
20	168	174	122	27.41	29.84	3.47
21	181	181	129	28.60	28.65	0.08
22	152	143	112	26.39	21.88	5.78
23	202	217	205	1.38	5.69	7.50
24	121	118	84	30.43	28.87	2.20

Table 5.7 Result of cardiac diameter of our proposed method compared with 2 experts. (continued)

Patient no.	Cardiac diameter (Cd)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
25	151	151	150	0.51	0.41	0.10
26	150	163	136	9.16	16.74	9.11
27	292	289	219	24.88	24.33	0.73
28	114	111	76	33.19	31.26	2.80
29	141	148	133	5.89	10.30	4.92
30	189	180	187	1.30	4.09	5.18
31	148	148	136	8.34	8.32	0.02
32	172	183	170	1.23	6.95	6.15
33	274	261	216	21.29	17.10	5.05
34	159	156	101	36.35	35.20	1.77
35	210	202	223	6.23	10.33	3.72
36	222	219	205	7.79	6.47	1.42
37	116	105	104	10.43	0.69	9.81
38	241	287	251	4.00	12.59	18.98
39	246	260	228	7.44	12.27	5.50
40	151	139	237	57.04	70.87	8.10
41	137	138	241	76.07	75.11	0.55
42	156	160	154	1.00	3.48	2.57
43	197	197	156	20.88	20.99	0.13
44	192	196	142	26.12	27.65	2.12
45	133	134	96	27.61	28.29	0.96
46	171	167	116	31.96	30.67	1.87
47	144	152	131	9.08	14.01	5.73
48	162	163	84	48.19	48.40	0.41
49	287	283	255	11.05	9.87	1.32
50	78	81	80	2.11	1.76	3.93
51	50	38	135	171.63	257.43	24.00
52	65	41	47	27.79	14.19	36.76
53	100	108	91	9.25	15.91	7.92
54	53	64	19	64.17	70.21	20.27
55	55	59	46	16.47	22.24	7.43
56	134	124	97	27.54	21.88	7.25

Table 5.7 Result of cardiac diameter of our proposed method compared with 2 experts. (continued)

Patient no.	Cardiac diameter (Cd)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
57	199	195	133	33.20	31.66	2.26
58	208	231	172	17.24	25.63	11.29
59	132	126	101	23.70	19.62	5.08
60	193	188	164	14.97	12.78	2.51
61	137	147	144	5.42	2.17	7.76
62	173	183	189	8.96	3.19	5.59
63	140	119	117	16.15	1.99	14.45
64	121	139	109	10.23	21.60	14.50
65	152	157	134	11.74	14.44	3.16
66	123	116	87	29.11	25.06	5.41
67	168	167	163	2.98	2.34	0.66
68	121	133	102	15.86	23.08	9.39
69	130	140	102	21.52	27.32	7.98
70	199	178	233	17.13	31.14	10.69
71	156	173	168	7.91	2.77	10.98
72	97	93	131	34.88	41.33	4.56
73	177	182	120	32.32	34.04	2.61
74	96	95	122	27.02	28.10	0.84
75	135	120	114	15.24	5.36	10.44
76	113	N/A	174	54.36	N/A	N/A
77	85	N/A	113	33.73	N/A	N/A
78	113	N/A	98	13.30	N/A	N/A
79	149	N/A	162	8.59	N/A	N/A
80	153	N/A	120	21.38	N/A	N/A
81	218	N/A	255	16.99	N/A	N/A
82	152	N/A	103	32.27	N/A	N/A
83	190	N/A	156	18.05	N/A	N/A
84	121	N/A	94	22.20	N/A	N/A
85	155	N/A	159	2.54	N/A	N/A
86	191	N/A	138	27.81	N/A	N/A
87	144	N/A	125	13.38	N/A	N/A
88	101	N/A	92	9.24	N/A	N/A
89	127	N/A	97	23.47	N/A	N/A

Table 5.7 Result of cardiac diameter of our proposed method compared with 2 experts. (continued)

Patient no.	Cardiac diameter (Cd)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
90	111	N/A	80	27.92		N/A
91	128	N/A	117	8.29	N/A	N/A
92	177	N/A	184	4.05	N/A	N/A
93	75	N/A	59	21.46	N/A	N/A
94	192	N/A	417	117.60	N/A	N/A
95	215	N/A	194	9.62	N/A	N/A
96	124	N/A	99	19.88	N/A	N/A
97	148	N/A	129	12.60	N/A	N/A
98	223	N/A	165	25.89	N/A	N/A
99	99	N/A	89	10.53	N/A	N/A
Average				21.23	22.07	6.17
Maximum				171.63	257.43	36.76
Minimum				0.51	0.41	0.02
Standard deviation				22.81	31.42	6.17

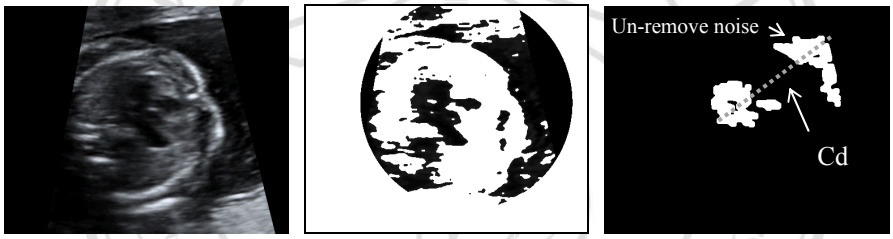
The average Cd error percentages compared to result of expert number 1 from 99 videos and 2 from 75 videos were 21.23% and 22.07%, respectively. The average of difference opinions between experts from 75 videos was 6.17%.

There are many factors that cause error in this experiment. Our proposed methodology measures only the heart chamber (heart structure), while the experts also include heart wall in their measurement. As already mentioned above on section 5.6, the biggest heart frame selection by our proposed methodology may differ from the experts. An example is shown in figure 5.8. Noise removal also affect heart structure measurement. The heart structure size was reduced when noises were removed (Table 5.4). It especially affected an image with small heart structure of patient number 54 as shown in figure 5.10. Some left over noises might include in the Cd measurement by the program. Therefore the value of Cd by the program was bigger than the expert Cd (Figure 5.11). From figure 5.7 the dark area connected to the heart chamber made heart structure become bigger than normal and affect on high value Cd. The direction of IVS given by the program were sometimes differences from the experts. Hence Cd measurement that is

perpendicular to IVS will be misplaced and also affected to Cd value calculation. An example is shown in figure 5.9.

(a) (b) (c)

Figure 5.10 An example of patient number 54 with small Cd, (a) small heart size (in dashed circle) in the image, (b) result of heart structure before removing noise and (c) small heart structure after removing noise.



(a) (b) (c)

Figure 5.11 An example of patient number 41 with too big Cd, (a) original ultrasound image, (b) result of heart structure before removing noise and (c) high Cd value due to un-remove noise.

5.8 Result of Cardiothoracic Ratio (CT ratio)

The CT ratio was computed by

$$\text{CT ratio} = \frac{Cd}{Td} \tag{5.6}$$

The error percentage of CT ratio was computed by

$$\%\ \text{error} = \frac{\text{abs}\left(CT_{program} - CT_{expert}\right)}{CT_{expert}} \times 100 \tag{5.7}$$

The % error between expert opinions was compute by

$$\%\ \text{difference opinion between experts} = \frac{\text{abs}\left(CT_{expert2} - CT_{expert1}\right)}{CT_{expert1}} \times 100 \tag{5.8}$$

The CT ratio average error percentage of each patient and percentage of different opinion between experts are shown in table 5.8. The average, maximum, minimum, and standard deviation are in the table.

Table 5.8 Result of CT ratio compared with 2 experts.

Patient no.	Cardiothoracic ratio (CT ratio)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
1	0.38	0.31	0.33	14.62	4.84	18.57
2	0.53	0.53	0.50	5.09	5.95	0.91
3	0.62	0.64	0.65	4.65	1.67	2.93
4	0.58	0.60	0.47	17.50	20.87	4.26
5	0.48	0.41	0.34	28.85	17.36	13.91
6	0.55	0.51	0.46	16.49	9.15	8.08
7	0.56	0.57	0.60	6.61	4.50	2.01
8	0.49	0.56	0.43	11.24	23.05	15.35
9	0.53	0.56	0.43	18.59	22.73	5.36
10	0.71	0.71	0.75	5.47	5.45	0.02
11	0.55	0.58	0.42	22.81	27.06	5.82
12	0.56	0.55	0.47	16.11	15.11	1.18
13	0.49	0.51	0.45	7.67	12.07	5.01
14	0.67	0.62	0.58	13.20	6.06	7.60
15	0.55	0.55	0.53	4.72	4.04	0.70
16	0.49	0.42	0.52	6.66	23.52	13.66
17	0.57	0.52	0.51	10.59	1.70	9.04
18	0.63	0.67	0.66	4.36	2.07	6.56
19	0.72	0.73	0.91	26.56	25.28	1.02
20	0.49	0.53	0.45	8.23	15.68	8.84
21	0.59	0.62	0.42	29.03	32.45	5.05
22	0.59	0.59	0.47	20.75	20.24	0.64
23	0.51	0.55	0.52	2.59	4.92	7.90
24	0.56	0.54	0.42	25.56	22.22	4.29
25	0.52	0.55	0.57	9.47	3.31	5.97
26	0.52	0.53	0.48	7.08	8.68	1.76
27	0.59	0.60	0.45	23.58	24.59	1.33
28	0.54	0.56	0.38	29.04	31.80	4.05
29	0.46	0.48	0.43	6.45	9.45	3.31

Table 5.8 Result of CT ratio compared with 2 experts. (continued)

Patient no.	Cardiothoracic ratio (CT ratio)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
30	0.74	0.69	0.74	0.06	6.70	6.33
31	0.50	0.53	0.51	0.13	4.61	4.97
32	0.52	0.53	0.60	14.37	12.55	1.62
33	0.56	0.54	0.39	30.54	27.80	3.80
34	0.63	0.63	0.42	33.53	34.03	0.76
35	0.49	0.46	0.58	17.47	25.92	6.70
36	0.62	0.60	0.59	5.68	2.10	3.65
37	0.45	0.41	0.33	28.15	20.48	9.64
38	0.58	0.67	0.55	5.77	18.02	14.95
39	0.65	0.66	0.62	4.95	6.13	1.25
40	0.46	0.43	0.74	60.31	71.70	6.63
41	0.54	0.58	0.73	36.10	25.91	8.09
42	0.56	0.59	0.53	6.46	10.92	5.00
43	0.58	0.57	0.49	16.35	14.47	2.19
44	0.56	0.58	0.39	29.38	32.37	4.42
45	0.38	0.40	0.29	22.45	26.83	5.98
46	0.56	0.56	0.40	28.23	28.08	0.21
47	0.47	0.49	0.43	7.05	11.77	5.34
48	0.44	0.47	0.26	42.62	45.68	5.63
49	0.61	0.62	0.55	9.77	11.74	2.23
50	0.70	0.70	0.71	0.95	1.14	0.19
51	0.59	0.46	1.17	98.24	155.20	22.32
52	0.63	0.38	0.47	25.75	22.46	39.37
53	0.43	0.45	0.43	0.34	3.70	4.20
54	0.44	0.71	0.16	63.88	77.70	61.95
55	0.44	0.49	0.38	14.41	22.42	10.32
56	0.62	0.56	0.47	24.40	16.72	9.22
57	0.68	0.66	0.45	33.21	31.69	2.23
58	0.67	0.72	0.58	13.65	19.84	7.71
59	0.65	0.68	0.51	22.55	25.74	4.29
60	0.51	0.50	0.46	9.59	7.87	1.87
61	0.47	0.51	0.52	9.85	2.30	7.38
62	0.49	0.51	0.56	13.37	9.64	3.40

Table 5.8 Result of CT ratio compared with 2 experts. (continued)

Patient no.	Cardiothoracic ratio (CT ratio)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
63	0.60	0.48	0.50	16.14	4.17	19.49
64	0.67	0.83	0.58	12.88	29.77	24.05
65	0.69	0.69	0.47	31.51	31.86	0.51
66	0.62	0.57	0.45	27.20	21.32	7.47
67	0.49	0.49	0.50	0.15	1.11	0.95
68	0.52	0.52	0.46	11.82	12.43	0.70
69	0.47	0.51	0.36	23.17	29.08	8.34
70	0.68	0.62	0.80	16.12	28.26	9.47
71	0.65	0.78	0.69	6.62	11.00	19.80
72	0.60	0.56	0.75	24.74	33.67	6.68
73	0.53	0.61	0.36	31.11	40.21	15.22
74	0.53	0.51	0.73	36.72	42.39	3.98
75	0.38	0.34	0.34	12.45	1.38	11.22
76	0.48	N/A	0.87	80.92	N/A	N/A
77	0.46	N/A	0.61	33.65	N/A	N/A
78	0.45	N/A	0.42	7.55	N/A	N/A
79	0.48	N/A	0.51	7.43	N/A	N/A
80	0.55	N/A	0.46	15.56	N/A	N/A
81	0.60	N/A	0.70	17.60	N/A	N/A
82	0.49	N/A	0.46	5.54	N/A	N/A
83	0.63	N/A	0.57	8.37	N/A	N/A
84	0.54	N/A	0.42	22.41	N/A	N/A
85	0.55	N/A	0.57	3.20	N/A	N/A
86	0.43	N/A	0.42	0.33	N/A	N/A
87	0.47	N/A	0.40	14.48	N/A	N/A
88	0.54	N/A	0.49	8.77	N/A	N/A
89	0.54	N/A	0.42	22.87	N/A	N/A
90	0.46	N/A	0.37	20.51	N/A	N/A
91	0.56	N/A	0.54	4.48	N/A	N/A
92	0.58	N/A	0.59	2.38	N/A	N/A
93	0.45	N/A	0.35	21.80	N/A	N/A
94	0.38	N/A	0.84	120.27	N/A	N/A
95	0.46	N/A	0.46	1.43	N/A	N/A
96	0.45	N/A	0.41	8.88	N/A	N/A
97	0.52	N/A	0.46	10.56	N/A	N/A

Table 5.8 Result of CT ratio compared with 2 experts. (continued)

Patient no.	Cardiothoracic ratio (CT ratio)			% Error program vs expert 1	% Error program vs expert 2	% error between expert opinion
	Expert1	Expert2	Program			
98	0.56	N/A	0.48	13.93	N/A	N/A
99	0.49	N/A	0.45	8.30	N/A	N/A
Average				18.64	20.36	7.56
Maximum				120.27	155.20	61.95
Minimum				0.06	1.11	0.02
Standard deviation				18.99	21.57	9.19

The average CT ratio errors were 18.64% and 20.36% compared to the results of expert number 1 from 99 videos and expert number 2 from 75 videos, respectively. The average difference of CT ratio between experts from 75 videos is 7.56 %. From the error of both Cd and Td as mentioned above made CT ratio result difference from experts. The CT ratio directly affects on cardiomegaly diagnosis.

5.9 Result of Cardiomegaly Diagnosis

Cardiomegaly diagnosis is based on the following criteria:
CT ratio >0.5 indicates abnormal or cardiomegaly detected.
CT ratio $\leq$0.5 indicates normal or no cardiomegaly detected.

In our confusion matrix, true positive means that the cardiomegaly diagnosed by expert is abnormal and our proposed method is abnormal. True negative means that expert's cardiomegaly diagnosis is normal and our proposed method is normal.

False positive means that expert's cardiomegaly diagnosis is normal but our proposed method is abnormal. False negative means that expert's cardiomegaly diagnosis is abnormal but our proposed method is normal.

The accuracy of cardiomegaly diagnosis can be calculated by

$$\text{Accuracy} = \frac{\text{True positive} + \text{True negative}}{\text{Total number of videos}} \times 100 \qquad (5.9)$$

The results of cardiomegaly detection were illustrated by the confusion matrix (Table 5.9 and 5.10). The correct cardiomegaly diagnosis is 58 out of 99 cases or 58.58%,

compared to expert number 1and 42 out of 75 cases or 56%, compared to expert number2.

Moreover, the true positive compared with expert number 1 was 33 cases, true negative was 25 cases, false positive was 9 cases, and false negative was 32 cases. Similarly, the true positive of our proposed method compared with expert number 2 was 29 cases, true negative was 13 cases, false positive was 4 cases, and false negative was 29 cases. The cardiomegaly diagnosis result of each patient is shown in table 5.11.

Table 5.9 Confusion matrix of cardiomegaly detection from 99 patients compared to expert 1.

		Our proposed method	
		Abnormal	Normal
Expert1	Abnormal	33	32
	Normal	9	25

Table 5.10 Confusion matrix of cardiomegaly detection from 75 patients compared to expert 2.

		Our proposed method	
		Abnormal	Normal
Expert2	Abnormal	29	29
	Normal	4	13

Table 5.11 Result of cardiomegaly diagnosis compared with 2 experts.

Patient no.	Cardiomegaly detection			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Correct = O, Incorrect= X	Correct = O, Incorrect= X	Correct = O, Incorrect= X
1	Normal	Normal	Normal	O	O	O
2	Abnormal	Abnormal	Normal	X	X	O
3	Abnormal	Abnormal	Abnormal	O	O	O
4	Abnormal	Abnormal	Normal	X	X	O
5	Normal	Normal	Normal	O	O	O
6	Abnormal	Abnormal	Normal	X	X	O
7	Abnormal	Abnormal	Abnormal	O	O	O

Table 5.11 Result of cardiomegaly diagnosis compared with 2 experts. (continued)

Patient no.	Cardiomegaly detection			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Correct = O, Incorrect= X	Correct = O, Incorrect= X	Correct = O, Incorrect= X
8	Normal	Abnormal	Normal	O	X	X
9	Abnormal	Abnormal	Normal	X	X	O
10	Abnormal	Abnormal	Abnormal	O	O	O
11	Abnormal	Abnormal	Normal	X	X	O
12	Abnormal	Abnormal	Normal	X	X	O
13	Normal	Abnormal	Normal	O	X	X
14	Abnormal	Abnormal	Abnormal	O	O	O
15	Abnormal	Abnormal	Abnormal	O	O	O
16	Normal	Normal	Abnormal	X	X	O
17	Abnormal	Abnormal	Abnormal	O	O	O
18	Abnormal	Abnormal	Abnormal	O	O	O
19	Abnormal	Abnormal	Abnormal	O	O	O
20	Normal	Abnormal	Normal	O	X	X
21	Abnormal	Abnormal	Normal	X	X	O
22	Abnormal	Abnormal	Normal	X	X	O
23	Abnormal	Abnormal	Abnormal	O	O	O
24	Abnormal	Abnormal	Normal	X	X	O
25	Abnormal	Abnormal	Abnormal	O	O	O
26	Abnormal	Abnormal	Normal	X	X	O
27	Abnormal	Abnormal	Normal	X	X	O
28	Abnormal	Abnormal	Normal	X	X	O
29	Normal	Normal	Normal	O	O	O
30	Abnormal	Abnormal	Abnormal	O	O	O
31	Abnormal	Abnormal	Abnormal	O	O	O
32	Abnormal	Abnormal	Abnormal	O	O	O
33	Abnormal	Abnormal	Normal	X	X	O
34	Abnormal	Abnormal	Normal	X	X	O
35	Normal	Normal	Abnormal	X	X	O
36	Abnormal	Abnormal	Abnormal	O	O	O
37	Normal	Normal	Normal	O	O	O
38	Abnormal	Abnormal	Abnormal	O	O	O

Table 5.11 Result of cardiomegaly diagnosis compared with 2 experts. (continued)

Patient no.	Cardiomegaly detection			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Correct = O, Incorrect= X	Correct = O, Incorrect= X	Correct = O, Incorrect= X
39	Abnormal	Abnormal	Abnormal	O	O	O
40	Normal	Normal	Abnormal	X	X	O
41	Abnormal	Abnormal	Abnormal	O	O	O
42	Abnormal	Abnormal	Abnormal	O	O	O
43	Abnormal	Abnormal	Normal	X	X	O
44	Abnormal	Abnormal	Normal	X	X	O
45	Normal	Normal	Normal	O	O	O
46	Abnormal	Abnormal	Normal	X	X	O
47	Normal	Normal	Normal	O	O	O
48	Normal	Normal	Normal	O	O	O
49	Abnormal	Abnormal	Abnormal	O	O	O
50	Abnormal	Abnormal	Abnormal	O	O	O
51	Abnormal	Normal	Abnormal	O	X	X
52	Abnormal	Normal	Normal	X	O	X
53	Normal	Normal	Normal	O	O	O
54	Normal	Abnormal	Normal	O	X	X
55	Normal	Normal	Normal	O	O	O
56	Abnormal	Abnormal	Normal	X	X	O
57	Abnormal	Abnormal	Normal	X	X	O
58	Abnormal	Abnormal	Abnormal	O	O	O
59	Abnormal	Abnormal	Abnormal	O	O	O
60	Abnormal	Abnormal	Normal	X	X	O
61	Normal	Abnormal	Abnormal	X	O	X
62	Normal	Abnormal	Abnormal	X	O	X
63	Abnormal	Normal	Normal	X	O	X
64	Abnormal	Abnormal	Abnormal	O	O	O
65	Abnormal	Abnormal	Normal	X	X	O
66	Abnormal	Abnormal	Normal	X	X	O
67	Normal	Normal	Normal	O	O	O
68	Abnormal	Abnormal	Normal	X	X	O
69	Normal	Abnormal	Normal	O	X	X
70	Abnormal	Abnormal	Abnormal	O	O	O

Table 5.11 Result of cardiomegaly diagnosis compared with 2 experts. (continued)

Patient no.	Cardiomegaly detection			Program vs expert 1	Program vs expert 2	Expert 1 vs expert2
	Expert1	Expert2	Program	Correct = O, Incorrect= X	Correct = O, Incorrect= X	Correct = O, Incorrect= X
71	Abnormal	Abnormal	Abnormal	O	O	O
72	Abnormal	Abnormal	Abnormal	O	O	O
73	Abnormal	Abnormal	Normal	X	X	O
74	Abnormal	Abnormal	Abnormal	O	O	O
75	Normal	Normal	Normal	O	O	O
76	Normal	N/A	Abnormal	X	N/A	N/A
77	Normal	N/A	Abnormal	X	N/A	N/A
78	Normal	N/A	Normal	O	N/A	N/A
79	Normal	N/A	Abnormal	X	N/A	N/A
80	Abnormal	N/A	Normal	X	N/A	N/A
81	Abnormal	N/A	Abnormal	O	N/A	N/A
82	Normal	N/A	Normal	O	N/A	N/A
83	Abnormal	N/A	Abnormal	O	N/A	N/A
84	Abnormal	N/A	Normal	X	N/A	N/A
85	Abnormal	N/A	Abnormal	O	N/A	N/A
86	Normal	N/A	Normal	O	N/A	N/A
87	Normal	N/A	Normal	O	N/A	N/A
88	Abnormal	N/A	Normal	X	N/A	N/A
89	Abnormal	N/A	Normal	X	N/A	N/A
90	Normal	N/A	Normal	O	N/A	N/A
91	Abnormal	N/A	Abnormal	O	N/A	N/A
92	Abnormal	N/A	Abnormal	O	N/A	N/A
93	Normal	N/A	Normal	O	N/A	N/A
94	Normal	N/A	Abnormal	X	N/A	N/A
95	Normal	N/A	Normal	O	N/A	N/A
96	Normal	N/A	Normal	O	N/A	N/A
97	Abnormal	N/A	Normal	X	N/A	N/A
98	Abnormal	N/A	Normal	X	N/A	N/A
99	Normal	N/A	Normal	O	N/A	N/A
Number of correct cardiomegaly detection				58	42	65
Number of incorrect cardiomegaly detection				41	33	10

As shown in the table, the above incorrect cardiomegaly detection were mostly come from false negative (program result indicates normal for abnormal case). The problem

of cardiomegaly diagnosis was smaller Cd value (section 5.7) affected on smaller CT ratio than experts result. In the opposite way high Cd creates high CT ratio and normality became abnormal. There were 23 normal and 19 abnormal cases that CT ratios were very close to 0.5 ($\pm$0.05). For example case 13 in the table 5.8 CT ratio value of expert number 1, expert number 2 and the program were 0.49, 0.51 and 0.45, respectively. A small error in CT ratio calculation could cause different diagnosis. The two experts also had some different opinions on cardiomegaly diagnosis.

Td and Cd measures by our program were mostly less than the results from the experts. We could possibly compute the missing value of Td and Cd. As already mentioned above that we measured Td from ribs after applying threshold which were rather thin and measure Cd from heart structure (heart chamber) without including heart tissue.

The difference values of Td and Cd from expert were averaged and added back to Td and Cd measured by the program to get more correct value. Then CT ratio, the error percentage of CT ratio, and cardiomegaly diagnosis were reintroduced as shown in table 5.12.

We called the added values as correction factors. Hence, the correction factors of Td and Cd were 18 and 29 pixels, respectively.

The resolution of ultrasound images used in our work is 71.984 pixels/inch. The correction factor should be recalculated if the algorithm was applied to different resolution. Hence the resolution factors of Td and Cd were 0.250 inch and 0.403 inch, respectively

Table 5.12 The result of CT ratio and cardiomegaly diagnosis after new calculation to improve the value of Td and Cd.

Patient no.	New Cd	New Td	CT ratio		% CT error	Cardiomegaly diagnosis	
	Program	Program	Program	Exppert1		Expert1	Program
1	81	178	0.46	0.38	19.58	Normal	Normal
2	192	345	0.56	0.53	5.99	Abnormal	Abnormal
3	219	310	0.71	0.62	13.66	Abnormal	Abnormal
4	236	454	0.52	0.58	9.65	Abnormal	Abnormal
5	132	322	0.41	0.48	13.91	Normal	Normal

Table 5.12 The result of CT ratio and cardiomegaly diagnosis after new calculation to improve the value of Td and Cd. (continued)

Patient no.	New Cd	New Td	CT ratio		% CT error	Cardiomegaly diagnosis	
	Program	Program	Program	Exppert1		Expert1	Program
6	168	318	0.53	0.55	4.76	Abnormal	Abnormal
7	194	295	0.66	0.56	17.74	Abnormal	Abnormal
8	160	322	0.50	0.49	2.37	Normal	Normal
9	238	501	0.48	0.53	10.61	Abnormal	Normal
10	175	213	0.82	0.71	15.81	Abnormal	Abnormal
11	172	356	0.48	0.55	11.83	Abnormal	Normal
12	170	320	0.53	0.56	4.52	Abnormal	Abnormal
13	216	435	0.50	0.49	2.26	Normal	Normal
14	188	291	0.65	0.67	3.68	Abnormal	Abnormal
15	162	270	0.60	0.55	8.36	Abnormal	Abnormal
16	167	284	0.59	0.49	20.93	Normal	Abnormal
17	281	511	0.55	0.57	3.79	Abnormal	Abnormal
18	174	239	0.73	0.63	15.85	Abnormal	Abnormal
19	350	369	0.95	0.72	31.31	Abnormal	Abnormal
20	151	291	0.52	0.49	6.59	Normal	Abnormal
21	158	326	0.48	0.59	17.86	Abnormal	Normal
22	141	256	0.55	0.59	7.21	Abnormal	Abnormal
23	234	410	0.57	0.51	11.99	Abnormal	Abnormal
24	113	218	0.52	0.56	8.09	Abnormal	Abnormal
25	179	282	0.63	0.52	22.34	Abnormal	Abnormal
26	165	299	0.55	0.52	5.98	Abnormal	Abnormal
27	248	502	0.49	0.59	16.56	Abnormal	Normal
28	105	217	0.48	0.54	10.06	Abnormal	Normal
29	162	324	0.50	0.46	7.64	Normal	Abnormal
30	216	272	0.79	0.74	7.85	Abnormal	Abnormal
31	165	287	0.58	0.50	13.90	Abnormal	Abnormal
32	199	303	0.66	0.52	25.97	Abnormal	Abnormal
33	245	572	0.43	0.56	23.69	Abnormal	Normal
34	130	261	0.50	0.63	20.32	Abnormal	Normal
35	252	403	0.63	0.49	26.85	Normal	Abnormal
36	234	367	0.64	0.62	2.41	Abnormal	Abnormal
37	133	337	0.39	0.45	13.01	Normal	Normal
38	280	475	0.59	0.58	1.15	Abnormal	Abnormal
39	257	386	0.67	0.65	2.17	Abnormal	Abnormal

Table 5.12 The result of CT ratio and cardiomegaly diagnosis after new calculation to improve the value of Td and Cd. (continued)

Patient no.	New Cd	New Td	CT ratio		% CT error	Cardiomegaly diagnosis	
	Program	Program	Program	Exppert1		Expert1	Program
40	266	339	0.78	0.46	70.43	Normal	Abnormal
41	270	348	0.78	0.54	44.64	Abnormal	Abnormal
42	183	311	0.59	0.56	4.75	Abnormal	Abnormal
43	185	338	0.55	0.58	6.06	Abnormal	Abnormal
44	171	380	0.45	0.56	18.98	Abnormal	Normal
45	125	346	0.36	0.38	4.28	Normal	Normal
46	145	306	0.47	0.56	15.54	Abnormal	Normal
47	160	321	0.50	0.47	7.18	Normal	Normal
48	113	347	0.33	0.44	26.81	Normal	Normal
49	284	484	0.59	0.61	3.23	Abnormal	Abnormal
50	109	131	0.83	0.70	18.76	Abnormal	Abnormal
51	164	133	1.23	0.59	108.48	Abnormal	Abnormal
52	76	119	0.64	0.63	1.99	Abnormal	Abnormal
53	120	228	0.53	0.43	21.92	Normal	Abnormal
54	48	138	0.35	0.44	20.66	Normal	Normal
55	75	139	0.54	0.44	21.56	Normal	Abnormal
56	126	226	0.56	0.62	9.58	Abnormal	Abnormal
57	162	313	0.52	0.68	23.31	Abnormal	Abnormal
58	201	316	0.64	0.67	4.81	Abnormal	Abnormal
59	130	218	0.60	0.65	8.51	Abnormal	Abnormal
60	193	374	0.52	0.51	1.29	Abnormal	Abnormal
61	173	294	0.59	0.47	23.93	Normal	Abnormal
62	218	356	0.61	0.49	24.19	Normal	Abnormal
63	146	252	0.58	0.60	2.79	Abnormal	Abnormal
64	138	205	0.67	0.67	0.66	Abnormal	Abnormal
65	163	303	0.54	0.69	21.61	Abnormal	Abnormal
66	116	212	0.55	0.62	11.14	Abnormal	Abnormal
67	192	347	0.55	0.49	11.87	Normal	Abnormal
68	131	242	0.54	0.52	4.86	Abnormal	Abnormal
69	131	300	0.44	0.47	7.23	Normal	Normal
70	262	311	0.84	0.68	23.06	Abnormal	Abnormal
71	197	260	0.76	0.65	16.43	Abnormal	Abnormal
72	160	193	0.83	0.60	38.24	Abnormal	Abnormal
73	149	347	0.43	0.53	18.88	Abnormal	Normal

Table 5.12 The result of CT ratio and cardiomegaly diagnosis after new calculation to improve the value of Td and Cd. (continued)

Patient no.	New Cd	New Td	CT ratio		% CT error	Cardiomegaly diagnosis	
	Program	Program	Program	Exppert1		Expert1	Program
74	151	186	0.81	0.53	52.95	Abnormal	Abnormal
75	143	358	0.40	0.38	4.31	Normal	Normal
76	203	217	0.94	0.48	93.69	Normal	Abnormal
77	142	202	0.70	0.46	53.07	Normal	Abnormal
78	127	252	0.50	0.45	11.29	Normal	Abnormal
79	191	335	0.57	0.48	19.89	Normal	Abnormal
80	149	278	0.54	0.55	1.91	Abnormal	Abnormal
81	284	381	0.75	0.60	24.83	Abnormal	Abnormal
82	132	240	0.55	0.49	12.02	Normal	Abnormal
83	185	290	0.64	0.63	1.96	Abnormal	Abnormal
84	123	242	0.51	0.54	5.99	Abnormal	Abnormal
85	188	297	0.63	0.55	14.67	Abnormal	Abnormal
86	167	343	0.49	0.43	14.31	Normal	Normal
87	154	332	0.46	0.47	0.34	Normal	Normal
88	121	205	0.59	0.54	9.50	Abnormal	Abnormal
89	126	251	0.50	0.54	6.97	Abnormal	Abnormal
90	109	235	0.46	0.46	0.04	Normal	Normal
91	146	236	0.62	0.56	10.15	Abnormal	Abnormal
92	213	328	0.65	0.58	12.04	Abnormal	Abnormal
93	88	187	0.47	0.45	5.44	Normal	Normal
94	446	514	0.87	0.38	127.40	Normal	Abnormal
95	223	444	0.50	0.46	8.73	Normal	Abnormal
96	128	262	0.49	0.45	9.74	Normal	Normal
97	158	298	0.53	0.52	2.96	Abnormal	Abnormal
98	194	359	0.54	0.56	3.86	Abnormal	Abnormal
99	118	215	0.55	0.49	11.45	Normal	Abnormal
Average					16.52	Correct diagnosis = 71	
Maximum					127.40		
Minimum					0.04	Incorrect diagnosis = 28	
Standard deviation					20.53		

After Td and Cd values have been improved, the percentage error of CT becomes less and the accuracy of cardiomegaly diagnosis increases. The average percentage error of CT ratio decreases from18.64% to 16.52% and the accuracy of the diagnosis increases from 58.58% to 71.72%.

The adjustment of Cd and Td help improving the accuracy. There were 22 incorrect become correct diagnosis and 9 cases of normal diagnosis from correct diagnosis become incorrect (false positive). However there were 7 from the 9 cases that CT ratio values were very close to 0.5 and these cases were wrongly classified after the improvement.