Original Research Paper

Automatic Detection of the End-Diastolic and End-Systolic from 4D Echocardiographic Images

¹Anas A. Abboud, ¹Rahmita Wirza Rahmat, ²Suhaini Bin Kadiman, ³Mohd Zamrin Bin Dimon, ¹Lili Nurliyana, ⁴M. Iqbal Saripan and ¹Hasan H. Khaleel

¹Department of Computer Science and Information Technology, UPM, 43400, Serdang, Malaysia
²National Heart Institute (IJN), No 145 Jalan Tun Razak, 50400 Kuala Lumpur, Malaysia
³Faculty of Medicine, Universiti Teknologi MARA(UiTM), 47000, Sungai Buloh, Malaysia
⁴Department of Computer and Communication Systems Engineering, Faculty of Engineering, UPM, 43400, Serdang, Malaysia

Article history Received: 05-03-2014 Revised: 26-05-2014 Accepted: 09-08-2014

Corresponding Author: Anas A. Abboud Department of Computer Science and Information Technology, University Putra Malaysia, 43400, Serdang, Malaysia Email: anasalabousyupm@gmail.com Abstract: Accurate detection of the End-Diastolic (ED) and End-Systolic (ES) frames of a cardiac cycle are significant factors that may affect the accuracy of abnormality assessment of a ventricle. This process is a routine step of the ventricle assessment procedure as most of the time in clinical reports many parameters are measured in these two frames to help in diagnosing and dissection making. According to the previous works the process of detecting the ED and ES remains a challenge in that the ED and ES frames for the cavity are usually determined manually by review of individual image phases of the cavity and/or tracking the tricuspid valve. The proposed algorithm aims to automatically determine the ED and ES frames from the four Dimensional Echocardiographic images (4DE) of the Right Ventricle (RV) from one cardiac cycle. By computing the area of three slices along one cardiac cycle and selecting the maximum area as the ED frame and the minimum area as the ES frame. This method gives an accurate determination for the ED and ES frames, hence avoid the need for time consuming, expert contributions during the process of computing the cavity stroke volume.

Keywords: End-Diastolic (ED) and End-Systolic (ES), Echocardiography Image, Stroke Volume, Right Ventricle (RV), Left Ventricle (LV), Three Dimensional Echocardiography (3DE), Proposed Method, QLAB System, Automatic Algorithm, Wall Motion

Introduction

Accurate detection of the End-Distally (ED) and End-Systolic (ES) stages of a cardiac cycle is a significant factor that can affect the accuracy of abnormality assessment of a ventricle (Ostenfeld *et al.*, 2012; Darvishi *et al.*, 2012). This process is a routine step of the ventricle assessment procedures, where often, in clinical reports, many parameters can be measured in these two stages to help in diagnosing and decision making (Umberto *et al.*, 2008). However, the process of detecting the ED and ES still a challenge for diagnosis because it was mostly done manually by tracking the cine loop during the clinical procedure, as in (Niemann *et al.*, 2007) or by optical tracking of the change of ventricle dimensions through watching the individual image faces of the ventricle during the cardiac cycle, as in (Aune *et al.*, 2009; Crean *et al.*, 2011; Dawood *et al.*, 2011).

Tracking the mitral valve motion is another method for detecting the ED and ES frame (Hussein *et al.*, 2011), where the ES stage is defined as the last frame before the opening of the mitral valve while the ED stage is the last frame before the closing for the mitral valve, as reported by (Nosir *et al.*, 1996). In the meanwhile, tracking the mitral valve together with the ventricle volume was presented by (Umberto *et al.*, 2008). ECG signal was used by (Zhu *et al.*, 2009) to



© 2015 Anas A. Abboud, Rahmita Wirza Rahmat, Suhaini Bin Kadiman, Mohd Zamrin Bin Dimon, Lili Nurliyana, M. Iqbal Saripan and Hasan H. Khaleel. This open access article is distributed under a Creative Commons Attribution (CC-BY) 3.0 license.

determine the ED and ES frame of the LV in order to generate a dynamic model of the LV. (Gopal *et al.*, 2007; Chua *et al.*, 2009) also used ECG to determine the ED frame through the R wave of the ECG and the ES frame was determined as the smallest cavity area. The biggest and smallest area of the RV cavity were visually tracked in three views; short axis, four chamber and coronal by (Ostenfeld *et al.*, 2012) to determine the ED and ES cardiac stages.

Gifani *et al.* (2010) presented an automatic detection method for ED and ES of LV from two and four chamber views using unsupervised learning algorithm (Locally Linear Embedding (LLE)) for three cardiac consecutive cycles. (Shalbaf *et al.*, 2011) performed image registration for echocardiographic images of 6 volunteers, distance computation and finally the classical Multi-Dimensional Scaling (MDS) used to construct low dimensional representation of 2D LV images to generate Iso-map. Then, they computed manifold model of seven phases of cardiac cycles to determine ED and ES stages automatically.

(Yuanfang *et al.*, 2011) determined ED and ES stages by tracking the mitral valve motion, based on (Nosir *et al.*, 1996)'s definition for the ED and ES stages. This method used 3D echo image of LV, by binaries and enhancing images in the pre-processing stage of their algorithm. Then, a dilation operation for different resolution scale was performed to avoid the blood flow effect. Finally, the number of connecting regions for 8-neighbore connectivity was computed. This method gives accurate results only with good quality echo image of mitral valve.

All of methods reviewed in this literature are time consuming; therefore, an accurate automatic detection for the ED and ES stages is highly required to assist specialists and interns in their clinical work.

Materials and Methods

The main goal of the proposed method is to enable automatic detection of the ED and ES frames from one cardiac cycle. This process is one of the steps of the main algorithm for measuring the RV stroke, which proposed automatic measuring for the ventricle stroke volume. Whereby the ventricle stroke volume is the volume of blood ejected from a ventricle at each beat of the heart. This is equal to the difference between the cavity volume at the End-Diastolic stage (EDV) and the cavity volume of at the End-Systolic stage (ESV) of the cardiac cycle according to (Barash *et al.*, 2011). This requires the determination of the ED and ES frames of the cardiac cycle and measuring the cavity volume at the end-diastolic and end-systolic as stated by (Klabunde, 2011). The cardiac cycle duration (or the number of frames in a cardiac cycle) is different from one patient to another. The ES frame position in the echocardiography video of a cardiac cycle (the ES stage of a cardiac cycle) is also different from one patient to another, as illustrated in Table 1. The ED frame as determined by the experts can be used as the first image in the cardiac cycle. It can also be considered as the frame following closure of the mitral valve, or the frame of the largest cavity in the cardiac cycle.

An automatic detection of the ED-ES frames is proposed, by measuring the area of the segmented cavity of the RV along a cardiac cycle for three slices in the middle region of the RV, as in Equation 1:

$$Area_{s(r)} = \sum_{i=1}^{n} \sum_{j=1}^{m} f(i,j), \text{ for all } f(i,j) > 0$$
 (1)

where, $Area_{s(r)}$ is the area of the segmented region in slice number r, where r = 8, 9, 10 and f(i,j) is the grayscale of the pixels in the segmented region.

These three slices (8, 9 and 10) which are located in the middle region of the RV cavity as presented in Fig. 1, is selected based on analyzing the structure and motion behavior of the 16 slices over a cardiac cycle for the patients in the dataset, of the RV cavity.

The details of selecting these slices are explained in the following sub-section.

Slice Selection

Selecting the slices from the middle region of the RV cavity is based on two anatomical facts.

First; the free wall area of the RV cavity in the middle region (fractional region) is broader than the inflow and out flow tract as illustrated in Fig. 2 and 3.

Therefore, for fully automatic detection of the ED-ES frame, the middle region of the cavity is sliced for this purpose. The middle region has a close intracardiac boundary along the cardiac cycle, while the inflow and outflow tract is affected by the motion of the valves (opening and closing) during the cardiac cycle. When the valve is closed, the region will be closed and segmentation includes only the intra cavity region.

However, when the valve is open, the segmentation will be growing out of the inflow and/or outflow tract. Figure 3 illustrates the intracardiac boundary of the RV in inflow, middle and out flow regions along different frames of one cardiac cycle video, for a patient.

Second; the amount of changes in the cavity area, in the middle region during the cardiac cycle is higher than the changes of the inflow and outflow tract. To experiment with this fact, the area of the 16 slices is computed for one cardiac cycle for one sample patient of the dataset.

Then the standard deviation and variance of the changing for total area of the cavity in each slice are computed for the comparison of each slice in one cardiac cycle. This is illustrated in Table 1-4 respectively and the corresponding diagram in Fig. 4-6, respectively for a sample of three patients of the data set.

The Tables and Diagrams clearly show that the middle region is highly affected along the cardiac cycle for which to be a candidate it has to be a good indicator of the ED and ES cardiac cycle frames.

By averaging the three previous samples, it can be concluded that the middle region has the highest fractional region (the region with maximum change in the cavity during the cardiac cycle), this is illustrated in Fig. 7.

Selecting the ED-ES Frames

In the proposed method, three slices are used to detect the ED and ES frames, as using three frames may provide accurate detection of the ED and ES frames. The diagram in Fig. 8 illustrates the method of detecting the ED and ES frames of the cardiac cycle.

As stated earlier in the proposed method, three slices are used to determine the frames of the ED and the ES stages. The reason for selecting three slices can be justified by computation analysis as in the following steps. Compute the change in the area of the segmented region in the frame ρ and compare it with the area of the frame ρ -1 of the same slice, for each of the three slices, as shown in Table 4.

According to the definition of the ED Frame, the maximum area of the segmented region is tracked from Table 4. The segmented areas for each of three slices (8, 9 and 10) in the first row are compared with its area in the second row. We can see that; for the slice number 8 the area is decrease in the second row and for slice number 9 and 10 the area increase in the second row, however the average of the area of the tree slices still the highest in the first row, thus we use the frame number in the first row as the ED stage of the cardiac cycle. Therefore the frame of first row can be considered as the ED frame.

By tracing the changes of the area, the minimum area in each slice falls in different frame numbers. For example in the segmented region area of slice 10, the area decreases in the frame 10, 11, until it reaches the minimum area in frame 12 and it starts to increase again in frame 13, as illustrated in Fig. 9. However, the segmented region area of slice 9 increases in frame 10, decreases to the minimum in frame 11 and then continues increasing in frames 12, 13... and so on. This procedure shown in Table 4 by the arrows.

To satisfy the accuracy of determining the ED and ES frames, the mean of the area is computed for three slices using Equation 2 and Equation 3 and the result is shown in Fig. 10.



Fig. 1. Three slices from the middle region of the RV cavity. Slice 8, Slice 9 and Slice 10 from left to right



Fig. 2. Right ventricle slices at inflow, middle and outflow regions of RV cavity



Fig. 3. The three regions (Inflow-Middle-Outflow) of the RV cavity for one patient of the data set, explain the changes in the cavity during a cardiac cycle and the effect of opening the TV and PV. The RV cavity boundary in the middle region (highlighted) is closed in the middle during the cardiac cycle



Fig. 4. Diagram of changing in the cavity area in each slice during one cardiac cycle for Patient 1



Fig. 5. Diagram of changing in the cavity area in each slice during one cardiac cycle for Patient 2



Fig. 6. Diagram of changing in the cavity area in each slice during one cardiac cycle for Patient 3



Fig. 7. Average of the standard deviation of the three patients, illustrating that the middle region is the greatest changing region affected in the cavity during the cardiac cycle



Fig. 8. Diagram of the method of the determination of ED and ES



Fig. 9. The area of three slices (8, 9 and 10) during the cardiac cycle



Fig. 10. The mean of areas for the three slices (8, 9 and 10) and the frames, the maximum area indicates the ED frame and the minimum area indicates the ES frame

Table 1. The changes of the cavity area for	r Patient 1, during one cardiac cycle in each slice (Si) are the slices $I = 1$ to 16. Ni is the frames	of one cardiac cycle video

N.Frame	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
N1	820	927	982	950	1195	909	817	960	1120	1247	1041	1233	1287	1435	928	1263
N2	700	802	881	998	1200	996	884	852	1092	1364	1091	1239	1311	1347	1002	1277
N3	726	745	832	972	1093	990	843	754	902	1064	1092	1111	1182	1264	916	900
N4	766	766	766	851	1013	915	804	658	679	973	854	1078	1140	1188	846	830
N5	796	664	660	726	906	850	718	592	584	916	756	953	1094	1054	603	735
N6	774	620	579	652	820	830	670	529	479	839	664	1017	1090	981	597	696
N7	685	573	530	630	790	801	638	542	416	485	688	973	926	1022	552	658
N8	654	548	536	657	772	783	586	490	510	504	726	1176	1302	1289	553	706
N9	599	554	543	687	787	807	599	492	402	508	788	1211	1348	1300	501	678
N10	603	551	518	580	721	778	584	508	388	498	765	1164	1404	1347	592	738
N11	603	556	534	520	779	608	577	413	344	446	632	843	1358	1290	597	742
N12	634	585	614	504	738	566	565	392	354	855	695	805	1125	1338	620	800
N13	684	667	620	596	637	706	484	419	579	855	679	822	1266	1151	609	742
N14	858	847	785	792	881	763	646	607	824	940	825	996	1170	1131	778	907
Variance	7255	15713	23065	27338	31697	15764	14836	28407	70943	87740	24971	23251	17619	19059	27425	39833
STDV	85	125	152	165	178	126	122	169	266	296	158	152	133	138	166	200

$$EDF = \rho \frac{\sum_{slc=1}^{3} Max(area_{slc})}{3}$$
(2)

$$ESF = \rho \frac{\sum_{slc=1}^{3} min(area_{slc})}{3}$$
(3)

where, is an indicator of the position of the frames in the cardiac cycle video, as declared in Table 6, EDF is the end diastolic frame, ESF is the end systolic frame and Area_{slc} is the area of the segmented region of the cavity in the slice.

For the sample data used in Fig. 9 and 10, the number of frames in one cardiac cycle is 68 frames. According to the computed segmented area and the frames, ES frame $\rho = 11$ is frame number 41 in the video.

Anas A. Abboud *et al.* / Journal of Computer Science 2015, 11 (1): 230.240 DOI: 10.3844/jcssp.2015.230.240

81 52 53 54 85 56 57 58 59 510 511 512 513 514 515 515 1600 N2 1794 173 1573 16805 1668 1730 1545 1215 2141 2208 2261 2273 2026 1724 1478 N4 1721 1649 1544 1500 1658 1720 1648 1515 1414 154 2000 2453 2044 1813 1648 N5 1540 1364 1328 1224 1328 1338 1648 1318 1264 138 1224 1318 1646 1318 2243 2314 1645 1540 1414 1141 1161 123 1231 1314 1640 1425 2489 2231 1435 1244 836 1414 1140 1241 1141 1141 1143 1144 1141 1144 1143 <td< th=""><th colspan="10">Table 2. The changes of slice area for Patient 2, during one cardiac cycle (Si) are the slices I =1 to 16, Ni is the frames of one cardiac cycle video</th></td<>	Table 2. The changes of slice area for Patient 2, during one cardiac cycle (Si) are the slices I =1 to 16, Ni is the frames of one cardiac cycle video																	
Ni 176. 172. 178. 178. 178. 178. 178. 178. 178. 187. 188. 188. 184. 184. 220. 286. 287. 261. 226. 286. 271. 241. 202. 178. 188. 186. 179. 184. 186. 179. 188. 186. 181. 184. 187. 184. 1		S1	S2	S3	S4	S5		S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
N2 1794 1794 1793 1870 1680 1630 1648 1400 515 2141 2308 2401 2273 2015 1605 N4 1721 1649 1544 1500 1679 1582 1635 129 1885 1988 2426 2716 2463 2026 1244 1813 1648 N6 1440 1363 1227 1318 1386 1388 1236 2439 2044 1813 1648 1548 1318 2264 2234 1646 1548 1549 1349 1066 1388 1449 1541 1443 1540 1349 1443 1340 1443 1340 2469 2237 1443 1444	N1	1763	1728	1678	1559	1776	,	1733	1854	1864	1854	2241	2620	2899	2615	2265	1950	1600
N3 1860 1751 1649 154 159 1679 1582 1515 1241 2082 2061 2022 1750 1573 N5 1540 1469 1346 1360 1454 1475 1683 1383 1884 1540 1464 1541 1248 1475 2261 2690 2453 2544 1494 1543 1564 N7 1353 1267 1231 1246 1724 1175 1262 1216 1242 1244 2292 1848 1560 1141 N0 1175 1167 1175 1262 1270 1532 1261 1272 1263 1279 1263 1279 1273 1292 1293 1361 1441 1484	N2	1794	1739	1713	1573	1805		1689	1830	1458	1499	2208	2568	2871	2621	2273	2015	1695
N4 1721 1649 154 150 1650 1657 1535 1988 2426 2716 2443 2022 1730 1573 N6 1440 1363 1278 1318 1346 1313 1648 1613 1648 1411 164 1365 2044 1813 1648 1717 1267 1211 1264 1238 1334 1445 1160 1366 1429 2246 2499 2246 1988 1440 1374 N0 1175 1170 11616 1306 1229 1231 1212 1232 1269 1271 2175 2179 2135 1992 1448 1068 N12 1105 1178 1191 1144 1134 1323 1209 1305 1299 1270 2175 2379 2356 1888 1318 1066 N12 1202 1318 1444 1144 1134 1332 1299 <td< td=""><td>N3</td><td>1860</td><td>1751</td><td>1694</td><td>1562</td><td>1780</td><td>)</td><td>1668</td><td>1720</td><td>1406</td><td>1515</td><td>2141</td><td>2508</td><td>2800</td><td>2461</td><td>2026</td><td>1724</td><td>1478</td></td<>	N3	1860	1751	1694	1562	1780)	1668	1720	1406	1515	2141	2508	2800	2461	2026	1724	1478
N5 1540 1456 1348 1348 1368 1377 1372 1372 1379 1343 1484 1400 1346 1348 1	N4	1721	1649	1554	1509	1679)	1582	1635	1329	1385	1988	2426	2716	2445	2052	1750	1573
N6 1440 1363 1278 1278 1278 1278 1278 1278 1278 1278 1267 121 1264 128 1271 1263 128 2272 2499 2346 1996 1588 1411 N9 1216 1173 1177 1206 1280 1278 1328 1373 1056 1292 1272 1292 1988 1470 1374 N10 1175 1170 1145 1110 1262 1273 1279 1231 1299 1271 249 2271 1952 1463 1066 N11 1282 1221 1141 1323 1209 1305 1299 1730 175 2479 2481 1888 1816 1616 N14 1300 1228 1328 1357 1616 1715 1815 1616 1715 1815 1616 1715 1818 1616 1719 1716 1813 1	N5	1540	1495	1346	1360	1454		1475	1608	1611	1248	1475	2261	2690	2453	2044	1813	1648
N7 1353 1240 117 126 126 127 1353 1374 1089 1318 2228 2344 2344 2344 2344 2344 2344 2344 2344 2344 2344 2345 1375 1164 1336 134 125 126 127 1353 1374 1365 1264 1275 2347 2345 1355 1392 1364 1304 1364 1344 1323 129 1364 1275 1275 1279 2348 1388 1364 1304	N6	1440	1363	1278	1318	1386	,	1338	1445	1511	1162	1293	2183	2578	2393	1971	1643	1562
N8 1278 1278 1278 1278 1278 1278 1278 1281 1215 1216 2182 2246 2249 2244 2240 2240 2240 2240 2240 2240 2240 2240 2251 1501 1144 N11 1168 1174 1130 1123 1202 1305 1202 1730 2175 2429 235 1952 1463 1080 N13 1222 1202 1190 1144 1144 1144 1144 1144 1144 1145 1130 1250 1612 1132 2422 2574 2348 1818 1446 1301 N14 1390 1558 1578 1573 1710 1713 1252 232 2140 2442 2041 1681 1364 Var. 5980 4536 44613 2476 47212 2423 211 15 131 1302 1325 155 <td< td=""><td>N7</td><td>1353</td><td>1267</td><td>1231</td><td>1264</td><td>1328</td><td></td><td>1271</td><td>1335</td><td>1394</td><td>1089</td><td>1318</td><td>2225</td><td>2459</td><td>2334</td><td>1966</td><td>1589</td><td>1411</td></td<>	N7	1353	1267	1231	1264	1328		1271	1335	1394	1089	1318	2225	2459	2334	1966	1589	1411
N9 1216 1170 1145 1162 1220 1276 1324 1023 1463 2169 2469 2469 2469 2469 2469 2479 1271 1137 1137 1137 1137 1137 1131 1131 1133 1141 1232 1209 1305 1229 1209 1305 1275 1210 1201 1203 1235 1323 1448 1460 1306 1141 1323 1328 1328 1228 1228 1236 1216 1114 1230 1205 1719 11452 1706 1143 1440 1430 1276 1376 1719 11452 1706 1241 2411 1416 1430 1440 1440 1440 1440 1440 1440 1440 1440 1440 1440 1440 1441 1440 1440 1440 1440 1440 1440 1440 1440 1441 1440 1441 14	N8	1278	1230	1177	1206	1280)	1228	1328	1373	1056	1251	2182	2494	2293	1884	1540	1396
N10 1175 1176 1124 1180 1160 1120 1224 1912 1005 1720 2137 2449 2273 1952 1501 1144 N11 1165 1178 1191 1146 1134 1123 1209 1305 1250 1613 2175 2429 2355 2569 2258 2566 1883 1463 1305 N14 1390 1328 1326 1443 1444 1417 1000 1578 1575 1571 1571 1571 1571 1719 1946 2422 2644 2442 2041 1681 1364 Var. 5980 4536 4463 2776 7712 2717 265 137 150 15 15 113 1949 498 Var. 5980 453 54 57 88 59 510 51 151 151 151 151 151 131 132 <t< td=""><td>N9</td><td>1216</td><td>1173</td><td>1167</td><td>1175</td><td>1262</td><td></td><td>1210</td><td>1279</td><td>1365</td><td>1056</td><td>1429</td><td>2246</td><td>2459</td><td>2262</td><td>1968</td><td>1470</td><td>1374</td></t<>	N9	1216	1173	1167	1175	1262		1210	1279	1365	1056	1429	2246	2459	2262	1968	1470	1374
N11 1168 1178 1191 1140 1305 1280 1270 1277 1273 2179 2137 2135 1923 1463 1068 N13 1222 1202 1100 1190 1342 1114 1233 1291 1250 1631 2232 2569 2236 1888 1316 1613 N15 1564 1439 1444 1477 1600 1567 1578 1575 1612 1816 2424 2441 1818 1346 N15 1630 1535 1719 1565 1710 1717 2137 157 150 115 113 134 1323 146 1346 1466 1366 1462 1717 2137 155 150 115 113 134 1323 146 1346 1465 1463 1463 1463 1463 1463 1463 1463 1463 1463 1463 1463 1463 14	N10	1175	1170	1145	1110	1262		1223	1276	1312	1023	1463	2169	2469	2273	1952	1501	1144
N12 1105 1178 1101 1146 1342 1141 1233 1230 1250	N11	1168	1214	1180	1160	1305		1280	1247	936	1052	1777	2137	2429	2271	1943	1463	1068
N13 1222 120 1328 1338 1061 1531 1441 1600 1567 1578 1575 1610 1515 1719 1325 1232 2033 211 2442 2443 2441 2411 1340 1238 1348 1466 Var 5998 45367 44613 2740 209 217 266 237 257 155 150 115 113 193 215 Var 5998 44213 211 165 116 1317 1502 1812 1874 1928 1812 1813 1814 1435 1416 1417 150 1615 1171 150 151 151 151 151 151 151 151 151 151	N12	1105	1178	1191	1146	1314		1323	1209	1305	1269	1730	2175	2479	2335	1952	1468	980
N14 1390 1328 1328 1236 1459 1235 1441 1406 1452 1706 277 2579 2348 1881 1436 1338 1236 1604 1500 1558 1442 1600 1657 1578 1575 1612 1513 2342 2049 2442 2041 1681 1346 Var 59980 45367 4613 2705 4717 4376 47212 4237 63179 10702 24103 2113 216 12864 37336 46388 STDV 244 213 211 165 204 209 217 206 151 151 150 113 12864 1479 1286 1307 1678 1878 1878 1878 1308 12864 1307 1678 1842 1942 1292 143 1216 111 193 1216 1116 101 1116 101 1101 1121 1317	N13	1222	1202	1190	1199	1342		1114	1253	1291	1250	1631	2253	2569	2256	1888	1318	1061
N15 1564 1439 1444 1417 1600 1567 1575 1612 1813 2424 2674 2379 1990 1528 1376 N17 1638 1536 1610 1515 1719 1685 1710 1719 1225 2033 2214 1204 2208 46398 N17 244 213 211 165 1717 4176 47212 4207 6179 10702 24103 2174 1238 108 46398 STDV 244 223 211 105 317 1502 118 118 114 1219 00 116 112 1219 01 1219 00 1219 01 1219 00 1219 00 1219 00 1219 01 1219 00 1219 01 1219 01 1219 01 1219 00 1219 01 1219 00 1219 01 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 00 1219 0	N14	1390	1328	1328	1256	1459)	1235	1461	1406	1452	1706	2277	2579	2348	1881	1436	1330
N16 1604 1500 1558 1482 1660 1626 1621 1616 1719 1324 2033 2211 2744 2141 1681 1346 Yar 59980 45367 44613 27405 41775 43767 47212 42437 63179 10709 24103 2274 13406 12864 37336 46398 STDV 244 213 211 165 204 209 217 206 51 327 155 150 115 113 193 215 Table Sameseo release restor Pattert 3, during one cardiac cycle (3) mer the siteset 1=1 to 16. Nie the frames or one cardiac cycle vietset 116 117 190 112 1874 192 1812 1874 192 122 232 2022 282 2022 188 1120 112 1811 112 112 181 1813 122 112 181 181 122 122 123 144 102 1161 100	N15	1564	1439	1484	1417	1600)	1567	1578	1575	1612	1813	2342	2674	2379	1990	1528	1279
N17 1638 1536 1610 1515 1717 4736 1719 1719 1225 2031 2714 2744 213 2016 13306 12364 37333 46389 STDV 244 213 211 165 2177 206 251 327 155 150 111 112 1330 46389 STDV 244 213 243 84 85 56 87 88 89 10 S11 S12 S13 S14 S15 S16 N1 2027 1488 968 1127 932 1105 1317 1502 1812 1874 142 222 2322 2023 1833 1121 101 101 101 1035 101 101 1035 101 101 1035 101 101 1035 101 101 1035 101 101 1035 101 101 1030 1131 1131	N16	1604	1500	1558	1482	1660)	1626	1621	1616	1719	1946	2427	2649	2442	2041	1681	1364
Var 5998.0 4357.0 417.0 217.0 244 210 210.0 211 200 251 251 257.0 134.0	N17	1638	1536	1610	1515	1719)	1685	1730	1719	1325	2053	2511	2764	2518	2067	1819	1498
STDV 244 213 211 165 204 209 217 206 251 327 155 150 115 113 193 215 Table 3. The changes of slice area for Patient 3, during one cardiac cycle (Si) are the slices 1=1 to 16, Ni is the frames of one cardiac cycle videous N1 2027 1488 968 1127 932 1105 1317 1502 1812 1874 1922 1222 2052 1915 1160 N2 1944 1482 971 1124 970 1121 1337 1526 1552 1781 1951 1924 2322 2023 1883 1122.00 N4 1757 1744 1646 1333 1779 1778 1879 1883 1930 945 1101 1007 953 1181 10145 1339 1748 1646 1202 1448 1466 1333 1779 1778 1879 1803 1814 1020 1114 1020 1014 <td>Var.</td> <td>59980</td> <td>45367</td> <td>44613</td> <td>27405</td> <td>41775</td> <td>4</td> <td>3767</td> <td>47212</td> <td>42437</td> <td>63179</td> <td>107029</td> <td>24103</td> <td>22794</td> <td>13406</td> <td>12864</td> <td>37336</td> <td>46398</td>	Var.	59980	45367	44613	27405	41775	4	3767	47212	42437	63179	107029	24103	22794	13406	12864	37336	46398
Table 3. The changes of slice area for Patient 3, during one cardiac cycle (Si) are the slices I = 1 to 16, Ni is the frames of one cardiac cycle video S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15 S16 N1 2027 1488 968 1127 932 1105 1317 1502 1812 1874 1928 1834 2101 2061 1947 1219.00 N2 1944 1482 971 1124 941 1106 1237 1526 1552 1781 1951 1924 2322 2023 1883 1102.00 N4 1757 1441 920 1119 978 1879 1881 1310 1435 1332 1797 1883 1828 1063.00 N5 1828 1307 945 1107 1347 1366 1393 184 1825 953.00 N6 1859 1397 945	STDV	244	213	211	165	204		209	217	206	251	327	155	150	115	113	193	215
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15 S16 N1 2027 1488 968 1127 932 1106 1317 1502 1812 1874 1928 1894 2101 2061 1947 1219.00 N2 1944 1482 971 1124 373 1526 1552 1781 1912 2322 2023 1883 1102.00 N4 1757 1441 920 1119 1007 953 1188 1310 1435 1339 1748 1640 2005 1803 1814 1022.00 N8 1805 1479 945 1101 1007 953 1184 1042 1505 1571 2000 1888 1814 1022.00 1884 182 1984 1825 953.00 N10 1662 1408 907 1074	Table 3	3. The chai	nges of sli	ce area fo	r Patient 3	, during or	ne caro	liac cycle	(Si) are th	ne slices I	=1 to 16,	Ni is the	frames o	f one care	liac cycle	video		
N1 2027 1488 968 1127 912 1105 1317 1502 1812 1874 1928 1894 2101 2061 1947 121900 N2 1944 1482 971 1124 941 1106 1298 1530 1579 1678 1942 1922 2322 2023 1881 1120.00 N3 1693 1493 949 1132 1735 1526 1552 1781 1951 1924 2322 2023 1883 1063.00 N5 1828 1390 945 1110 1007 953 1188 1310 1435 1339 1747 1778 1880 1803 1814 1022.00 N6 1805 1479 990 1085 961 859 197 147 1366 1955 1812 1944 1919 1820 97.00 N10 1662 1408 1970 148 1990 1685		S1	S2	S3	S4	S5	S6	S7	S 8	S9	S1	0 S1	11 5	512	S13	S14	S15	S16
N2 1944 1482 971 1124 941 1106 1298 1530 1579 1678 1942 1922 2322 2052 1915 1160.00 N3 1693 1493 949 1132 970 1121 1337 1526 1552 1781 1951 1924 2322 2023 1883 1102.00 N4 1757 1441 920 1117 1050 1068 1202 1344 1466 1339 1778 1778 1789 1880 1812 1063.00 N6 1859 1397 945 1101 1007 953 1188 1310 1435 1596 1571 2008 1888 1815 992.00 N8 1805 1479 909 1088 961 145 1596 1571 2000 1888 2008 2012 1726 874.00 N11 1661 1415 1596 1571 2000	N1	2027	1488	968	1127	932	1105	1317	1502	1812	2 187	4 19	28 1	894	2101	2061	1947	1219.00
N3 1693 1493 949 1132 970 1121 1337 1526 1552 1781 1951 1924 2232 2003 1883 1122.00 N4 1757 1441 920 1119 978 1115 1222 1443 1466 1393 1779 1778 1879 1880 1828 1063.00 N5 1828 1390 945 1101 1007 953 1184 1310 1435 1332 1748 1640 2005 1803 1814 1022.00 N7 1847 1429 907 1078 960 902 1197 1347 1396 1955 1812 1984 1919 1825 953.00 N9 1749 1425 907 1078 965 888 1057 1021 1437 1646 1951 1883 2008 1984 1825 953.00 N11 1691 1415 866 105	N2	1944	1482	971	1124	941	1106	1298	1530	1579	9 167	8 19	42 1	922	2322	2052	1915	1160.00
N4 1757 1441 920 1119 978 1115 1222 1433 1516 1512 1881 1873 2257 2009 1853 1093.00 N5 1828 1390 945 1117 1050 1068 1202 1344 1466 1393 1779 1778 1879 1880 1828 1063.00 N6 1859 1397 945 1101 1007 953 1188 1310 1443 1330 1748 1640 2005 1803 1812 1922.00 N8 805 1479 909 1085 961 859 1092 1197 1347 1396 1551 1812 1984 1919 853.00 N10 1662 1408 907 1046 947 844 1072 1059 1622 1503 1977 1916 2039 1989 1750 874.00 N111 1617 1335 817 1	N3	1693	1493	949	1132	970	1121	1337	1526	1552	2 178	19	51 1	924	2322	2023	1883	1122.00
NS 1828 1390 945 1117 1050 1068 1202 1344 1466 1393 1778 1879 1880 1828 1063.00 N6 1859 1397 945 1101 1007 953 1188 1310 1435 1330 1748 1640 2005 1803 1814 1022.00 N7 1847 1429 909 1085 961 859 1092 1197 1347 1396 1955 1812 1984 1919 1825 953.00 N10 1662 1408 907 1076 944 441 1057 1052 1531 1977 1916 2039 1989 1750 874.00 N11 1675 1387 833 1122 970 938 1019 966 1459 1541 2108 1883 2060 2012 1726 864.00 N11 1675 1385 817 1138 974	N4	1757	1441	920	1119	978	1115	1222	1443	1516	5 151	2 18	81 1	873	2257	2009	1853	1093.00
N6 1859 1377 945 1101 1007 953 1188 1310 1435 1339 1748 1640 2005 1803 1814 1022.00 N8 1805 1479 909 1085 961 859 1092 1197 1347 1396 1955 1812 1984 1919 1825 933.00 N9 1749 1425 907 1078 950 848 1096 1145 1505 1571 2000 1888 2008 1984 1820 917.00 N10 1662 1408 907 1046 947 844 1072 1059 1622 1503 1977 1916 2039 1989 1750 874.00 N11 1675 1387 833 1122 970 938 1019 966 1459 1541 2108 1853 2035 1949 1629 783.00 N13 1657 1385 817 </td <td>N5</td> <td>1828</td> <td>1390</td> <td>945</td> <td>1117</td> <td>1050</td> <td>1068</td> <td>1202</td> <td>1344</td> <td>1466</td> <td>5 139</td> <td>3 17</td> <td>79 1</td> <td>778</td> <td>1879</td> <td>1880</td> <td>1828</td> <td>1063.00</td>	N5	1828	1390	945	1117	1050	1068	1202	1344	1466	5 139	3 17	79 1	778	1879	1880	1828	1063.00
N7 1847 1429 921 1098 969 909 1156 1263 1532 1302 1949 1772 2148 1888 1815 992.00 N8 1805 1479 909 1085 961 859 1092 1197 1347 1396 1955 1812 1984 1919 1825 953.00 N9 1749 1425 907 1076 940 844 1072 1059 1622 1503 1977 1916 2039 1989 1750 874.00 N11 1661 1415 866 1059 965 888 1003 952 1621 1551 2113 1861 2062 1620 1626 793.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1944 1893 2035 1949 1629 778.00 N15 1644 1314 1912 <td>N6</td> <td>1859</td> <td>1397</td> <td>945</td> <td>1101</td> <td>1007</td> <td>953</td> <td>1188</td> <td>1310</td> <td>1435</td> <td>5 133</td> <td>9 17</td> <td>48 1</td> <td>640</td> <td>2005</td> <td>1803</td> <td>1814</td> <td>1022.00</td>	N6	1859	1397	945	1101	1007	953	1188	1310	1435	5 133	9 17	48 1	640	2005	1803	1814	1022.00
N8 1805 1479 909 1085 961 859 1092 1197 1347 1396 1955 1812 1984 1919 1825 953.00 N9 1749 1425 907 1078 950 848 1096 1145 1556 1571 2000 1888 2008 1984 1820 917.00 N11 1691 1415 866 1059 965 888 1057 1021 1437 1646 1951 1883 2060 2012 1726 864.00 N12 1675 1387 831 1122 970 938 1019 966 1459 1541 2108 1853 2044 2022 1662 822.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1944 1893 2035 1949 1629 778.00 N15 1644 1314 819 126 </td <td>N7</td> <td>1847</td> <td>1429</td> <td>921</td> <td>1098</td> <td>969</td> <td>909</td> <td>1156</td> <td>1263</td> <td>1532</td> <td>2 130</td> <td>19-</td> <td>49 1</td> <td>772</td> <td>2148</td> <td>1888</td> <td>1815</td> <td>992.00</td>	N7	1847	1429	921	1098	969	909	1156	1263	1532	2 130	19-	49 1	772	2148	1888	1815	992.00
N9 1749 1425 907 1078 950 848 1096 1145 1596 1571 2000 1888 2008 1984 1820 917.00 N10 1662 1445 866 1059 965 888 1005 1021 1437 1646 1951 1883 2060 2012 1726 864.00 N11 1657 1387 833 1122 970 938 1019 966 1459 1541 2108 1858 2044 2022 1692 822.00 N14 1657 1385 817 1138 974 843 1003 952 1651 1551 2113 1861 2062 1990 1666 733.00 N14 1629 1373 814 1006 1024 850 940 972 1651 1557 1941 183 2035 1949 152 750.00 N16 1642 1334 841 1159 1090 1030 1127 1157 1837 1637 1922 <t< td=""><td>N8</td><td>1805</td><td>1479</td><td>909</td><td>1085</td><td>961</td><td>859</td><td>1092</td><td>1197</td><td>1347</td><td>7 139</td><td>6 19</td><td>55 1</td><td>812</td><td>1984</td><td>1919</td><td>1825</td><td>953.00</td></t<>	N8	1805	1479	909	1085	961	859	1092	1197	1347	7 139	6 19	55 1	812	1984	1919	1825	953.00
N10 1662 1408 907 1046 947 844 1072 1059 1622 1503 1977 1916 2039 1989 1750 874.00 N11 1691 1415 866 1059 965 888 1017 1021 1437 1646 1951 1883 2060 2012 1726 864.00 N113 1657 1387 833 1122 970 938 1019 966 1459 1541 2113 1861 2062 1990 1666 793.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1994 1893 2035 1949 1629 778.00 N15 1644 1313 819 1126 1015 870 941 1113 1691 2016 1978 2021 1728 1575 792.00 N16 1642 1338 880 1203<	N9	1749	1425	907	1078	950	848	1096	1145	1596	5 157	1 20	00 1	888	2008	1984	1820	917.00
N11 1691 1415 866 1059 965 888 1057 1021 1437 1646 1951 1883 2060 2012 1726 864.00 N12 1675 1387 833 1122 970 938 1019 966 1459 1541 2108 1858 2044 2022 1692 822.00 N13 1657 1385 817 1138 974 843 1003 952 1621 1551 2113 1861 2062 1990 1669 778.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1994 1893 2035 1949 1629 778.00 N16 1642 1338 841 1159 1002 1127 1157 1837 1637 1922 1783 1853 1707 1494 710.00 N17 1645 1338 840 1203<	N10	1662	1408	907	1046	947	844	1072	1059	1622	2 150	3 19	77 1	916	2039	1989	1750	874.00
N12 1675 1387 833 1122 970 938 1019 966 1459 1541 2108 1858 2044 2022 1692 822.00 N13 1657 1385 817 1138 974 843 1003 952 1621 1551 2113 1861 2062 1990 1666 793.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1994 1893 2035 1949 1629 778.00 N15 1644 1314 819 1126 1015 870 941 1115 1684 1691 2016 1978 2060 1908 1575 792.00 N17 1617 1331 822 1204 1061 127 1157 1837 1637 1922 1783 1853 1707 1494 710.00 N18 1645 1338 880 1203 </td <td>N11</td> <td>1691</td> <td>1415</td> <td>866</td> <td>1059</td> <td>965</td> <td>888</td> <td>1057</td> <td>1021</td> <td>1437</td> <td>7 164</td> <td>6 19</td> <td>51 1</td> <td>883</td> <td>2060</td> <td>2012</td> <td>1726</td> <td>864.00</td>	N11	1691	1415	866	1059	965	888	1057	1021	1437	7 164	6 19	51 1	883	2060	2012	1726	864.00
N13 1657 1385 817 1138 974 843 1003 952 1621 1551 2113 1861 2062 1990 1666 793.00 N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1994 1893 2035 1949 1629 778.00 N15 1644 1314 819 1126 1015 870 941 1115 1684 1691 2001 1934 2084 1911 1605 807.00 N16 1642 1303 822 129 1061 998 1108 1132 1795 1670 1955 1959 2021 1728 1547 750.00 N18 1645 1338 840 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1717 1494 755.00 N20 1632 1472 1648 1072 948 1093 1313 1712 1487 2011 1765	N12	1675	1387	833	1122	970	938	1019	966	1459) 154	1 21	08 1	858	2044	2022	1692	822.00
N14 1629 1373 814 1060 1024 850 940 972 1651 1567 1994 1893 2035 1949 1629 778.00 N15 1644 1314 819 1126 1015 870 941 1115 1684 1691 2001 1934 2084 1911 1605 807.00 N16 1642 1305 825 1129 1073 966 1062 1143 1713 1696 2016 1978 2060 1908 1575 792.00 N17 1617 1331 822 1204 1061 998 1108 1132 1795 1670 1955 1959 2021 1728 1547 750.00 N18 1645 1338 880 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1717 1494 804.00 N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011	N13	1657	1385	817	1138	974	843	1003	952	1621	155	21	13 1	861	2062	1990	1666	793.00
N15 1644 1314 819 1126 1015 870 941 1115 1684 1691 2001 1934 2084 1911 1605 807.00 N16 1642 1305 825 1129 1073 966 1062 1143 1713 1696 2016 1978 2060 1908 1575 792.00 N17 1617 1331 822 1204 1061 998 1108 1132 1795 1670 1955 1959 2021 1728 1547 750.00 N18 1645 1378 841 1159 1000 1127 1157 1837 1637 1922 1783 1816 1719 1494 710.00 N20 1632 1421 960 1168 1072 948 1082 1245 1547 1472 1988 1736 1816 1737 1496 804.00 N21 1611 1456 1008 <t< td=""><td>N14</td><td>1629</td><td>1373</td><td>814</td><td>1060</td><td>1024</td><td>850</td><td>940</td><td>972</td><td>1651</td><td>156</td><td>7 19</td><td>94 1</td><td>893</td><td>2035</td><td>1949</td><td>1629</td><td>778.00</td></t<>	N14	1629	1373	814	1060	1024	850	940	972	1651	156	7 19	94 1	893	2035	1949	1629	778.00
N16 1642 1305 825 1129 1073 966 1062 1143 1713 1696 2016 1978 2060 1908 1575 792.00 N17 1617 1331 822 1204 1061 998 1108 1132 1795 1670 1955 1959 2021 1728 1547 750.00 N18 1645 1338 840 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1719 1490 755.00 N20 1632 1421 960 1168 1072 948 1093 1313 1712 1487 2011 1765 1816 1719 1490 755.00 N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011 1765 1918 1781 1503 832.00 N22 1700 1472	N15	1644	1314	819	1126	1015	870	941	1115	1684	169	20	01 1	934	2084	1911	1605	807.00
N17 1617 1331 822 1204 1061 998 1108 1132 1795 1670 1955 1959 2021 1728 1547 750.00 N18 1645 1378 841 1159 1090 1030 1127 1157 1837 1637 1922 1783 1853 1707 1494 710.00 N19 1645 1338 880 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1719 1490 755.00 N20 1632 1421 960 1168 1072 948 1082 1245 1547 1472 1988 1756 1876 1737 1496 804.00 N21 1611 1456 1008 1191 1037 948 1093 1761 1504 1995 1757 1915 1738 1507 863.00 N22 1700 1472 1024 1191 1046 1245 1428 1721 1558 1920 1733 193	N16	1642	1305	825	1129	1073	966	1062	1143	1713	3 169	6 20	16 1	978	2060	1908	1575	792.00
N18 1645 1378 841 1159 1090 1030 1127 1157 1837 1637 1922 1783 1853 1707 1494 710.00 N19 1645 1338 880 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1719 1494 710.00 N20 1632 1421 960 1168 1072 948 1082 1245 1547 1472 1988 1756 1876 1737 1496 804.00 N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011 1765 1918 1781 1503 832.00 N22 1700 1472 1024 1192 1037 1058 1264 1393 1761 1504 1995 1757 1915 1738 1557 923.00 N23 1700 1473 1627 1453 1790 1584 1932 1792 1917 1788 1	N17	1617	1331	822	1204	1061	998	1108	1132	1795	5 167	0 19	55 1	959	2021	1728	1547	750.00
N19 1645 1338 880 1203 1092 1020 1158 1205 1808 1441 1993 1756 1816 1719 1490 755.00 N20 1632 1421 960 1168 1072 948 1082 1245 1547 1472 1988 1756 1876 1737 1496 804.00 N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011 1765 1918 1781 1503 832.00 N22 1700 1472 1024 1192 1037 1058 1264 1393 1761 1504 1995 1757 1915 1738 1507 863.00 N23 1700 1409 1004 1213 1059 1046 1245 1428 1721 1558 1920 1769 1923 1743 1535 932.00 N24 1678 1423 1002 1007 1089 1270 1453 1790 1584 1932	N18	1645	1378	841	1159	1090	1030	1127	1157	1837	7 163	7 19	22 1	783	1853	1707	1494	710.00
N20 1632 1421 960 1168 1072 948 1082 1245 1547 1472 1988 1756 1876 1737 1496 804.00 N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011 1765 1918 1781 1503 832.00 N22 1700 1472 1024 1192 1037 1058 1264 1393 1761 1504 1995 1757 1915 1738 1507 863.00 N23 1700 1409 1004 1213 1059 1046 1245 1428 1721 1558 1920 1769 1923 1743 1535 923.00 N24 1678 1423 1022 1207 1007 1089 1270 1453 1700 1587 1920 1733 1934 1788 1587 1032.00 N25 1661 1421	N19	1645	1338	880	1203	1092	1020	1158	1205	1808	3 144	1 19	93 1	756	1816	1719	1490	755.00
N21 1611 1456 1008 1191 1037 948 1093 1313 1712 1487 2011 1765 1918 1781 1503 832.00 N22 1700 1472 1024 1192 1037 1058 1264 1393 1761 1504 1995 1757 1915 1738 1507 863.00 N23 1700 1409 1004 1213 1059 1046 1245 1428 1721 1558 1920 1769 1923 1743 1535 923.00 N24 1678 1423 1022 1207 1007 1089 1270 1453 1790 1584 1932 1792 1917 1788 1571 1030.00 N25 1669 1456 1012 1191 1046 1071 1281 1493 1700 1584 1920 1733 1934 1788 1631 1062.00 N26 1661 1421 1009 1198 978 1074 1257 1480 1697 1610	N20	1632	1421	960	1168	1072	948	1082	1245	1547	147	2 19	88 1	756	1876	1737	1496	804.00
N22 1700 1472 1024 1192 1037 1058 1264 1393 1761 1504 1995 1757 1915 1738 1507 863.00 N23 1700 1409 1004 1213 1059 1046 1245 1428 1721 1558 1920 1769 1923 1743 1535 923.00 N24 1678 1423 1002 1207 1007 1089 1270 1453 1790 1584 1932 1792 1917 1788 1571 1030.00 N25 1669 1456 1012 1191 1046 1071 1281 1493 1700 1587 1920 1733 1934 1788 1587 1032.00 N26 1661 1421 1009 1198 978 1074 1271 1477 1670 1586 1920 1733 1934 1788 1631 1062.00 N27 1677 1428 1000 1175 973 1058 1254 1492 1643 1590	N21	1611	1456	1008	1191	1037	948	1093	1313	1712	2 148	37 20	11 1	765	1918	1781	1503	832.00
N23 1700 1409 1004 1213 1057 1056 1245 1428 1721 1558 1920 1769 1923 1743 1535 923.00 N24 1678 1423 1022 1207 1007 1089 1270 1453 1790 1584 1932 1792 1917 1788 1555 923.00 N25 1669 1456 1012 1191 1046 1071 1281 1493 1700 1587 1920 1733 1934 1788 1587 1032.00 N26 1661 1421 1009 1198 978 1074 1271 1477 1670 1586 1929 1814 1933 1798 1631 1062.00 N27 1677 1428 10001 1085 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N28 1645 1421 983 1174 1001 1085 1255 1500 1663 1568 1942 1859	N22	1700	1472	1024	1192	1037	1058	1264	1393	1761	150	4 19	95 1	757	1915	1738	1507	863.00
N24 1678 1423 1002 1207 1007 1089 1270 1433 1790 1584 1932 1792 1917 1788 1571 1030.00 N25 1669 1456 1012 1191 1046 1071 1281 1493 1700 1587 1920 1733 1934 1788 1571 1030.00 N26 1661 1421 1009 1198 978 1074 1271 1477 1670 1586 1929 1814 1933 1798 1631 1062.00 N27 1677 1428 1000 1175 973 1058 1257 1480 1697 1610 1961 1828 1955 1814 1682 1065.00 N28 1645 1421 983 1174 1001 1085 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N29 1642 1418 981 1157 947 1053 1255 1500 1663 1568	N23	1700	1409	1004	1213	1059	1046	1245	1428	1721	155	8 19	20 1	769	1923	1743	1535	923.00
N25 1669 1456 1012 1191 1046 1071 1281 1493 1700 1587 1920 1733 1934 1788 1587 1032.00 N26 1661 1421 1009 1198 978 1074 1271 1477 1670 1587 1920 1733 1934 1788 1587 1032.00 N26 1661 1421 1009 1198 978 1074 1271 1477 1670 1586 1929 1814 1933 1798 1631 1062.00 N27 1677 1428 1000 1175 973 1058 1257 1480 1697 1610 1961 1828 1955 1814 1682 1065.00 N28 1645 1421 983 1174 1001 1085 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N29 1642 1418 981 1157 947 1053 1255 1500 1663 1568 <	N24	1678	1423	1022	1207	1007	1089	1270	1453	1790) 158	4 19	32 1	792	1917	1788	1571	1030.00
N26 1661 1421 1009 1191 1016 1011 1271 1477 1670 1586 1929 1814 1933 1708 1631 1062.00 N27 1677 1428 1000 1175 973 1058 1257 1480 1697 1610 1961 1828 1955 1814 1632 1062.00 N28 1645 1421 983 1174 1001 1085 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N29 1642 1418 981 1157 947 1053 1255 1500 1663 1568 1942 1829 2019 1879 1744 1076.00 N30 1666 1440 974 1158 939 1079 1273 1498 1680 1570 1940 1777 1986 1900 1786 1070.00 N31 1629 1451 987 1162 934 1089 1293 1632 1672 1582 <td< td=""><td>N25</td><td>1669</td><td>1456</td><td>1012</td><td>1191</td><td>1046</td><td>1071</td><td>1281</td><td>1493</td><td>1700</td><td>) 158</td><td>19</td><td>20 1</td><td>733</td><td>1934</td><td>1788</td><td>1587</td><td>1032.00</td></td<>	N25	1669	1456	1012	1191	1046	1071	1281	1493	1700) 158	19	20 1	733	1934	1788	1587	1032.00
N27 1677 1428 1000 1175 973 1051 1071 1171 1070 1071 1072 1071 1072 1071 1072 1071 1071 1072 1071 1071 1072 1071 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1072 1071 1071 1071 1072 1073 1073 1273 1498 1680 1570 1940 1777 1986 1900 1786 1070.00 1073 1073 1073 1073 1632	N26	1661	1421	1009	1198	978	1074	1271	1477	1670) 158	6 19	29 1	814	1933	1798	1631	1062.00
N28 1645 1421 983 1175 1055 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N29 1645 1421 983 1175 947 1053 1254 1492 1643 1590 1966 1863 2014 1854 1712 1082.00 N29 1642 1418 981 1157 947 1053 1255 1500 1663 1568 1942 1829 2019 1879 1744 1076.00 N30 1666 1440 974 1158 939 1079 1273 1498 1680 1570 1940 1777 1986 1900 1786 1070.00 N31 1629 1451 987 1162 934 1089 1293 1632 1672 1582 1916 1765 1971 1887 1830 1075.00 N32 1613 1534 1009 1152 939 1084 1307 1609 1646 1623 1911 1	N27	1677	1428	1000	1175	973	1058	1257	1480	1697	7 161	0 19	61 1	878	1955	1814	1682	1065.00
N29 1612 1603	N28	1645	1421	983	1174	1001	1085	1254	1492	1643	150	0 19	66 ¹	863	2014	1854	1712	1082.00
N20 1612 1710 1617 1747 1605 1205 1605	N29	1642	1418	981	1157	947	1053	1254	1500	1663	159	8 10	47 I	829	2019	1879	1744	1076.00
N31 1629 1451 987 1162 934 1089 1273 1632 1672 1576 1776 1777 1800 1800 1780 1770 N31 1629 1451 987 1162 934 1089 1273 1632 1672 1582 1916 1775 1971 1887 1830 1075.00 N32 1613 1534 1009 1152 939 1084 1307 1609 1646 1623 1911 1869 2032 1918 1847 1077.00 N33 1715 1540 1029 1154 962 1109 1313 1596 1826 1795 2043 1911 2059 2036 1864 1087.00 Var. 9707 3088 5129 2121 2486 9088 13227 41985 15755 15279 5071 5854 14033 12125 19847 19723.00 STDV 98 55 <td>N30</td> <td>1666</td> <td>1440</td> <td>974</td> <td>1158</td> <td>939</td> <td>1079</td> <td>1255</td> <td>1498</td> <td>1680</td> <td>) 150</td> <td>10 10</td> <td>40 1</td> <td>777</td> <td>1986</td> <td>1900</td> <td>1786</td> <td>1070.00</td>	N30	1666	1440	974	1158	939	1079	1255	1498	1680) 150	10 10	40 1	777	1986	1900	1786	1070.00
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	N31	1629	1451	987	1162	934	1089	12/3	1632	1673	, 157	2 10	16 1	765	1971	1887	1830	1075.00
N33 1715 1540 1029 1154 962 1109 1313 1596 1826 1795 2043 1911 2052 1918 1647 1077.00 N33 1715 1540 1029 1154 962 1109 1313 1596 1826 1795 2043 1911 2059 2036 1864 1087.00 Var. 9707 3088 5129 2121 2486 9088 13227 41985 15755 15279 5071 5854 14033 12125 19847 19723.00 STDV 98 55 71 46 49 95 115 204 125 123 71 76 118 110 140 140.44	N32	1613	1534	1009	1152	930	1084	1295	1600	16/4	5 167	2 19	11 1	869	2032	1918	1847	1077.00
Var. 9707 3088 5129 2121 2486 9088 13227 41985 15755 15279 5071 5854 14033 2125 19847 19723.00 STDV 98 55 71 46 49 95 115 204 125 123 71 76 118 110 140.41 140.44	N32	1715	1540	1020	1154	962	11004	1212	1504	1874	5 170	.5 19 15 20	11 I 43 I	911	2052	2036	186/	1087.00
STDV 98 55 71 46 49 95 115 204 125 123 71 76 118 110 140 140.44	Var	9707	3088	5129	2121	2486	9088	1313	41085	15755	, 1/9 5 1527	10 20 10 50	71 5	854	4033	12125	19847	19723.00
	STDV	98	55	71	46	49	95	115	204	125	5 12	3	71	76	118	110	140	140.44

Results

The proposed method was implemented on an LV dataset of 12 patients. The ED and ES of these data were determined by cardiologists from the National Heart Institute (IJN, KL. Malaysia), during a routineclinicalassessment. Using the current available software A-QLAB, the proposed method was implemented on the LV dataset, although the A-QLAB software was designed for quantifying the LV and mitral

valve. The ED and ES Frames were determined manually by the expert during the routine clinical test for 12 patients. By default, the expert assumed the ED was the first frame of the cardiac cycle for all patients' data. The ES was determined by visual tracing of the cavity area changes and mitral valve together by considering the frame with the minimum area of the cavity and a closed mitral valve. The ED and ES frames that were selected by the experts and determined automatically by the proposed method were recorded and shown in Table 5.

Normalized frame	The frame position	Segmented region	Segmented region	Segmented region	
(Indicator) ρ	in the cardiac cycle	area of slice 8	area of slice 9	area of slice 10	Mean of area
1	1	1476	1160	1226	1732
2	5	1401↓	1173↑	1248↑	1730
3	9	1378	1111	1225	1604
4	13	1396	1053	1163	1508
5	17	1258	933	989	1480
6	21	1125	846	865	1363
7	25	1062	771	851	1262
8	29	1020	754	834	1246
9	33	886	685	783	1229
10	37	889↑	693↑	769	1188
11	41	826↓	633↓	743↓	1098
12	43	854↑	649↑	702↓	1262
13	47	836↓	677↑	722↑	1265
14	51	1036↑	785↑	825↑	1429
15	55	1210	1171	896	1549
16	59	982	971	990	1607
17	63	1314	1005	1051	1582

Table 4. Computed area for three slices and the average, the rows indicate the changes in the area of the segmented region of the frame ρ compared with frame ρ -1

Table 5. Determining the position of the ED and ES frame in the video of a cardiac cycle for 12 patients

	Manual (by expert)		Automatic (proposed method				
Patient no.	 ED	ES	ED	ES			
1	1	24	1	24			
2	1	34	2	34			
3	1	41	1	41			
4	1	31	5	31			
5	1	39	1	39			
6	1	25	1	25			
7	1	43	5	43			
8	1	37	1	37			
9	1	32	1	32			
10	1	58	1	58			
11	1	32	1	32			
12	1	35	1	35			

Table 6. Computing the EDA, to assess the effect of the variance in the frame number between the manual and the proposed automatic method. *e* is the absolute difference between the EDA of experts and automatic method

	Manual metho	d		Automatic met	hod			
Frame detection Method	Cardiac stage			Cardiac stage	Absolute difference between the EDA			
Patient no.	ED frame no.	EDA	ES frame no.	ED frame no.	EDA	ES frame no.	of two methods (e)	
P1	1	94	24	1	99	24	5	
P2	1	141	34	2	134	34	7	
P3	1	130	41	1	121	41	9	
P4	1	104	31	5	110	31	6	
P5	1	98	39	1	100	39	2	
P6	1	93	25	1	97	25	4	
P7	1	81	43	5	87	43	6	
P8	1	137	37	1	132	37	5	
Р9	1	89	32	1	93	32	4	
P10	1	99	58	1	98	92	1	
P11	1	86	32	1	86	32	0	
P12	1	90	35	1	90	35	0	

From Table 5, it can be pointed out that the ES frames which were determined by the proposed method matches the ES frames which were selected by the experts for all of the 12 patients in the dataset.

Discussion

The result for ED frame selection is different between the proposed method and the experts by 2.5% of the data set (as in 2nd, 4th and 7th patients).

To analyse the effect of these difference in selecting the ED frames for these three patients P2, P5 and P7 using the proposed automatic method and the ED frame that selected manually by the experts for these three patients P2, P5 and P7. The absolute difference of the area of the cavity region in the End Dystonic frame (EDA) for both (automatic and manual) methods (e) is computed as declared in Table 6. Then the cavity volume at the ED is computed for the cases that have an error in detecting the ED frame for the patients P2, P5 and P7 is 0.05 mL, 0.077 mL and 0.04 mL respectively, regarding to the LV volume at End-Diastolic frame (EDV = 120 mL) according to (Schlosser et al., 2005) and (Blalock et al., 2013) this values represent 0.4, 0.6 and 0.3% of the EDV volume, which is a very small value and can be neglected.

Conclusion

This research is presented to explain the proposed algorithm of the automatic ED and ES frame detection from one cardiac cycle based on the medical definition of the ED as the maximum volume of the cavity and the ES as the minimum cavity volume in the cardiac cycle. By computing the segmented area for three slices in the middle region of the RV cavity, this region is selected after analysing the changes in the cavity area in three regions of the cavity Inflow, Middle and Outflow regions. The middle region was the most significant part in the changing area along a cardiac cycle and not the inflow and outflow tract. That is because the area of the free wall in this region is wider than the area of the free wall in the inflow and outflow tract, as illustrated in Fig. 2.

The cavity region is segmented for the three slices, along the video of one cardiac cycle and then the average of the slice area is computed. The frames of the maximum area and minimum area are detected as the ED and ES frames respectively. The results of the proposed algorithm have been validated using the A-QLAB system and datasets of different patients.

Funding Information

The authors have no support or funding to report.

Author's Contributions

All authors equally contributed in this work.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

- Aune, E., M. Baekkevar, O. Rodevand and J.E. Otterstad, 2009. The limited usefulness of realtime 3-dimensional echocardiography in obtaining normal reference ranges for right ventricular volumes. Cardiovascular Ultrasound, 7: 35-35. DOI: 10.1186/1476-7120-7-35
- Barash, P.G., B.F. Cullen, R.K. Stoelting, M.C. Stock and M.K. Cahalan, 2011. Clinical anesthesia. 1st Edn., Lippincott Williams and Wilkins, ISBN-10: 1451122977, pp: 1760.
- Blalock, S., F. Chan, D. Rosenthal, M. Ogawa and D. Maxey *et al.*, 2013. Magnetic resonance imaging of the right ventricle in pediatric pulmonary arterial hypertension. Pulmonary Circulat., 3: 350-355. DOI: 10.4103/2045-8932.114763
- Chua, S., R.A. Levine, C. Yosefy, D.M. Handschumacher and J. Chu *et al.*, 2009. Assessment of right ventricular function by realtime three-dimensional echocardiography improves accuracy and decreases interobserver variability compared with conventional two-dimensional views. Eur. J. Echocardiography, 10: 619-624. DOI: 10.1093/ejechocard/jep013
- Crean, A.M., N. Maredia, G. Ballard, R. Menezes and G. Wharton et al., 2011. 3D Echo systematically right underestimates ventricular volumes compared to cardiovascular magnetic resonance in adult congenital heart disease patients with moderate or severe RV dilatation. J. Cardiovascular Magnetic Resonance, 13: 78-78. DOI: 10.1186/1532-429X-13-78
- Dawood, T., M.P. Schlaich, N. Straznicky, M. Grima and C. Ika-Sari *et al.*, 2011. Renal denervation: A potential new treatment modality for polycystic ovary syndrome. J. Hypertens., 29: 991-996. DOI: 10.1097/HJH.0b013e328344db3a
- Darvishi, S., H. Behnam, M. Pouladian and N. Samiei, 2012. Measuring left ventricular volumes in twodimensional echocardiography image sequence using level-set method for automatic detection of enddiastole and end-systole frames. Res. Cardiovasc Med., 1: 39-45. DOI: 10.5812/cardiovascmed.6397

- Gifani, P., H. Behnam, A. Shalbaf and Z.A. Sani, 2010. Automatic detection of end-diastole and end-systole from echocardiography images using manifold learning. Phy. Measure., 31: 1091-1091. DOI: 10.1088/0967-3334/31/9/002
- Gopal, A.S., O. Ebere, C.J. Chizor, I.S. Alan, K. S. Rena and T.W. Schapiro *et al.*, 2007. Normal values of right ventricular size and function by real-time 3-dimensional echocardiography: Comparison with cardiac magnetic resonance imaging. J. Am. Soci. Echocardiography, 20: 445-455. DOI: 10.1016/j.echo.2006.10.027
- Hussein, S.M., N.N. Batada, S. Vuoristo, R.W. Ching and R. Autio *et al.*, 2011. Copy number variation and selection during reprogramming to pluripotency. Nature, 471: 58-62. DOI: 10.1038/nature09871
- Klabunde, R. 2011. Cardiovascular physiology concepts. Cardiovascular physiology concepts. 1st Edn., Illustrated, Lippincott Williams and Wilkins, Philadelphia, ISBN-10: 1451113846, pp: 243.
- Niemann, P.S., L. Pinho, T. Balbach, C. Galuschky, M. Blankenhagen and M. Silberbach *et al.*, 2007. Anatomically oriented right ventricular volume measurements with dynamic three-dimensional echocardiography validated by 3-tesla magnetic resonance imaging. J. Am. Coll. Cardiol., 50: 1668-1676. DOI: 10.1016/j.jacc.2007.07.031
- Nosir, Y.F.M., P.M. Fioretti, W.B. Vletter, B.E. Boersma and A. Salustri *et al.*, 1996. Accurate measurement of left ventricular ejection fraction by three-dimensional echocardiography a comparison with radionuclide angiography. Circulation, 94: 460-466. DOI: 10.1161/01.CIR.94.3.460
- Ostenfeld, E., M. Carlsson, K. Shahgaldi, A. Roijer and J. Holm, 2012. Manual correction of semi-automatic three-dimensional echocardiography is needed for right ventricular assessment in adults; validation with cardiac magnetic resonance. Cardiovascular Ultrasound, 10: 1-1. DOI: 10.1186/1476-7120-10-1

- Schlosser, T., K. Pagonidis, C.U. Herborn, P. Hunold and K.U. Waltering *et al.*, 2005. Assessment of left ventricular parameters using 16-MDCT and new software for endocardial and epicardial border delineation. Am. J. Roentgenol., 184: 765-773. DOI: 10.2214/ajr.184.3.01840765
- Shalbaf, A., H. Behnam, P. Gifani and Z. Alizadeh-Sani, 2011. Automatic detection of end systole and end diastole within a sequence of 2-D echocardiographic images using modified Isomap algorithm. Proceedings of the 1st Middle East Conference on Biomedical Engineering, Feb. 21-24, IEEE Xplore Press, Sharjah, pp: 217-220. DOI: 10.1109/MECBME.2011.5752104
- Umberto, B., M. Davide and S. Ovidio, 2008. Automatic computation of left ventricle ejection fraction from dynamic ultrasound images. Patt. Recognit. Image Anal., 18: 351-358. DOI: 10.1134/S1054661808020247
- Yuanfang, G., V. Yao, K. Tsui, M. Gebbia and M.J. Dunham *et al.*, 2011. Nucleosome-coupled expression differences in closely-related species. BMC Genom., 12: 466-466. DOI: 10.1186/1471-2164-12-466
- Zhu, Y., X. Papademetris, J.S. Albert and S.D. James, 2009. A Dynamical Shape Prior for Lv Segmentation from RT3D Echocardiography. In: Medical Image Computing and Computer-Assisted Intervention-MICCAI, Yang, G.Z., D. Hawkes, D. Rueckert, A. Noble, C. Taylor (Eds.)., Springer Berlin Heidelberg, ISBN-10: 978-3-642-04267-6, pp: 206-213.