Improved Ejection Fraction Measurement on Cardiac Image Using Optical Flow

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Abstract—— **Echocardiography give information about shape, size, and function of heart to create the cardiac image. One of the most commonly measurement in echocardiography is Ejection Fraction. Ejection fraction (EF) used to calculate volume of left ventricle function which oblige doctor to create shape of left ventricle in two phase manually. In this research, we propose an improved system that able to used creating shape of heart semi-automatically by Optical Flow method. The result shape of it we used to measure EF. The result shown that the error in ejection fraction measurement using shape resulted of optical flow tracking 10.468%. It means that optical flow can improvement ejection fraction measurement which focus on reconstruct left ventricle's semi-automatically by using tracking result. So, doctor shouldn't create the shapes in systole and diastole phase manually.**

Keywords—echocardiography; ejection fraction; optical flow; biplane; perpendicular line

I. INTRODUCTION

Cardiovascular disease (CVD) will continue to be trends with the annual number of death which rise from 17.5 million in 2012 to 22.2 million by 2030[1]. It is important for doctor to determine kind of cardiovascular disease by using echocardiography test[6]. Echocardiography is clinical practice used for assessing left ventricular function and diagnosing heart disease[2]. The evaluation of it only rely based on the accuracy of and physicians experience. This may cause the results of the analysis differ from each doctor and makes it difficult to determine the actual state[12].

The ejection fraction (EF) is the most important common clinical test used to measurement how well your heart when pumping out blood, diagnosing, and tracking heart failure [3]. A highly recommended method for calculating ejection fraction is Biplane Disk Summation method (modified Sympson's rule) [4]. The first step of Biplane disk summation is creating the biplane. Biplane is one algorithm to measure volume of left ventricle by creating shape of it. Usually doctor should make the left ventricle's shape while systole and the diastole phase manually, so it takes longer time. Riyanto Sigit's research applied segmentation in echocardiography video using watershed, snake and triangle equation method. The error value of triangle is lower than snake and watershed method [8,9,10,11,12].

This research provides a system that able to reconstruct left ventricle's shape semi-automatically and it used to ejection fraction value. By using optical flow as tracking method, we can follow the movement and get the shape. We believe this system can be used to facilitate doctor in measuring ejection fraction as the assessment of left ventricle function become easier.

II. RELATED WORKS

Echocardiography images have low signal-to-noise ratio with signal. There are some methods such as active contours, neural network, euclidean space has been tried to get boundary of left ventricle segmentation by semi-automatically and automatic. The result of active contours which user has to draw an initial contour close to the LV. Combined with K-means clustering can be used to get the left ventricle shape although have error prone everywhere the endocardium border is poorly the apex. This method also are prohibitively slow mathematically and complicated algorithm. The other method is using Neural Network which are fully automated. The system provide highly accurate results, though it there is no way to apply a correction to the segmentation result[15].

III. METHODOLOGY

In this chapter, explained about design system that used in this research. This system uses dataset tested from Dr.Soetomo Surabaya Hospital. To improve ejection fraction measurement, we focus on creating shapes in two phase semi-automatically by utilizing Optical Flow result. The recommendation to calculate ejection fraction using 2 cardiac image from 2 angle, AP4CH (Apical Four Chamber) as the horizontal part and AP2CH (Apical Two Chamber) as the vertical part.. So, by using 2 viewpoint we can find the volume of left ventricle heart which illustrated in Fig.1.

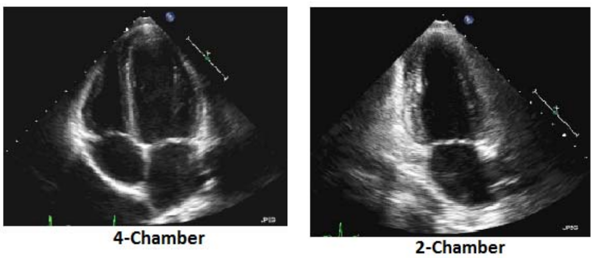


Fig.1. Viewpoint of Apical Two Chamber and Four Chamber

To create this system, the detail steps are shown on Fig.2

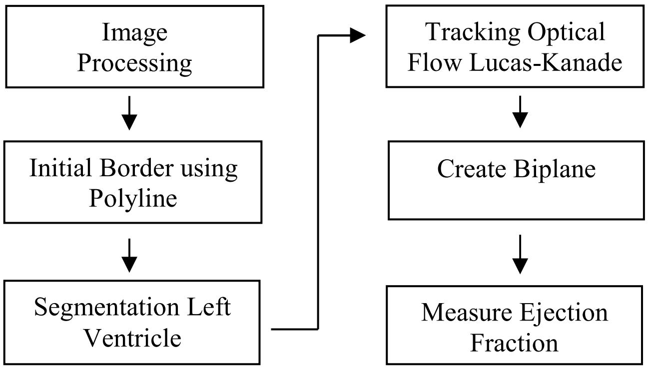


Fig.2. Schematic Diagram of the Algorithm

A. Preprocessing

Preprocessing is used to improvement the image of echocardiography which has a lot of noise. Some of the preprocessing steps include Gaussian filter and grayscale. Optical Flow need brightness constancy, so it require Gaussian Filter. Gaussian filter can eliminate noise by removing high-frequency image. High frequency image has significant different of grayscale value with its neighbors. Then grayscale is used to convert gray degrees to simplfy the image model into binary image for thresholding step.

B. Initial border in the first frame using Polyline

Polyline is one of the function in openCV that used to draw polygonal curves. Basically, polyline work as same as basic line, which is set of intersection point. Polyline used to draw the border of left ventricle on cardiac image to separate from other part of heart. Fig 3 shows how to mark the image using dots or circle, then polyline connect each dots.

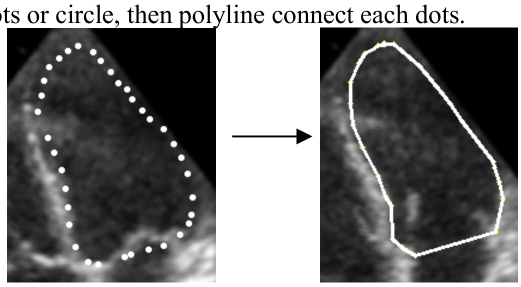


Fig.3. Initial left ventricle border by polyline

C. Segmentation

Apical Four Chamber video represented 4 part there are left and right ventricle, left and right atrium. In this research, we only used left ventricle to calculate fraction ejection. To separate left ventricle with the other part of heart, we are using thresholding and show the contour of it. Thresholding value has been define, and the result will show on Fig 4.

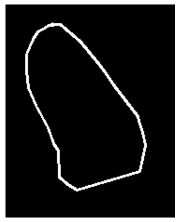


Fig.4. Preprocessing Result

D. Tracking Optical Flow

Optical Flow is predicting the movement of an image based on its intensity derivative on a sequential image. If applied to a 2D image this represents how far a pixel image moves between 2 image frames. Lucas-Kanade is one of the method in computer vision used to estimate of Optical Flow. By combining information from several nearby pixels, Lucas-Kanade's method can resolve the ambiguity.

Pyramidal Lucas-Kanade works on first of the highest pyramid layer. The result of Lucas Kanade is used to reference the starting point to work on the layer below. This continues until it reaches the lowest level. Based on a paper submitted by Bouquet (Bouquet, 2000), the Lucas-Kanade Pyramidal algorithm can be explained as follows: Let I and J be two 2D gray scale images. The two values $I(x) = I(x; y)$ and $J(x) = J(x; y)$ are the gray scale values of two images at the location $x = [x; y]\ T$, with x and y being the two coordinates pixel from the generic image point x. Image I will be referenced as the first image, and image J as the second image.

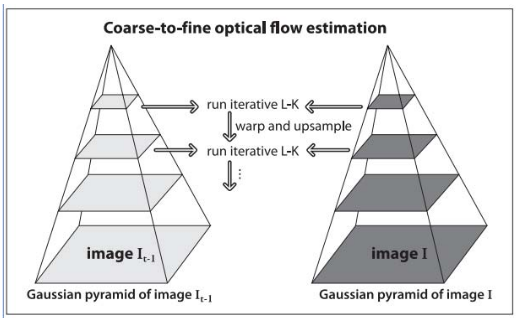


Fig.5. Pyramidal Lucas Kanade

E. Biplane

Biplane is one of the requirements to calculate ejection fraction which measure the volume of living heart. *American Society of Echocardiography and European Association of Cardiovascular Imaging* recommended biplane disc summation method is suited for shape distortions in measuring left ventricle volume using 2D images[4]. Volume of left ventricle is calculated from the summation of a stack of elliptical disc in biplane. The height of each disk is calculated as a fraction based on the longer of the two lengths from the two chamber and four chamber images[7]. There are four steps to create biplane 1)find the centroid of left ventricle, 2)making ROI, 3)get the shortest length, and 4)making perpendicular line along the top to bottom of left ventricle heart. This is the explanation of created biplane:

1) Centroid of Left Ventricle

Centroid of left ventricle is used as reference in creating ROI area. The moment method implemented to find the centroid of LV contour shows on Fig.6. This system changes image to binary value, so the result are just black and white. The white value is 1, so it is declared as object, meanwhile black value is 0 as background. The moment method work by counting pixel where the image is nonzero. Because the picture has been changed into binary images, it makes the calculation easier. The eq.(1) is formula to summarize a shape given image $I(x,y)$ as order moment. If I and J is zero these then would be just counting up number of nonzero pixel. Which means that $M_{0,0}$ is the area. Because the area of the picture it's nonzero, only sums and counting of nonzero pixel.

$$M_{i,j} = \sum_x \sum_y x^i y^j I(x,y) \quad (1)$$

So, the central moment are equation

$$\mu_{p,q} = \sum_x \sum_y (x-\bar{x})^p (y-\bar{y})^q I(x,y) \quad (2)$$

while, $\bar{x}$ is the average of x, so the average x would just be the same of all the Xs devided by how many Xs there area. For M_{01} is first moment in X and $M_{0,0}$ all of the area

$$\bar{x} = \frac{M_{10}}{M_{00}} \qquad \bar{y} = \frac{M_{01}}{M_{00}} \quad (3)$$

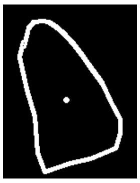


Fig.6. Centroid of Contour

2) ROI (Region of Interest)

ROI is used to limit the area which is needed to the find shortest length's step. Using rectangle shape, we only use left and right side to created several diagonal lines shown in fig 7

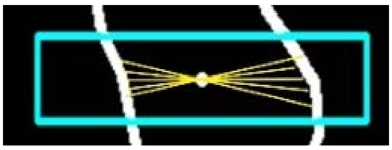


Fig.7. Rectangle area to limit while searching the shortest legth

3) Find the shortest length

The diagonal line is created starting from upper-left and lower right corner to lower-right and upper-right. The formula called Euclidean Distance can calculate distance between 2 location :

$$d(x,y) = \sqrt{(x_1-y_1)^2 + (x_2-y_2)^2} \quad (4)$$

This system eliminates the larger length and updates it as the shortest value. In the Fig,8 shows that red line presents the shortest distance.

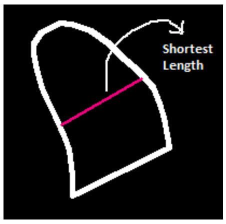


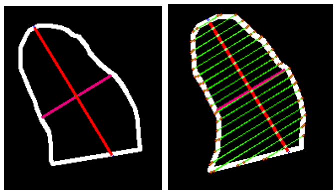
Fig.8. The shortest length

4) Perpendicular Line

Perpendicular line created along of top to bottom of left ventricle. The equation (5)(6)(7)(8) is calculated one by one for x axis and y axis. So the .x and .y in eq.(5) until eq.(8) it means for x axis and y axis. The equation to create perpendicular line are

- Find the middle-point of minimum distance's line
  medPoint.x = A.x + B.y / 2
  medPoint.y = A.x + B.y / 2 (5)
- Calculate vector B to A
  Vektor.x = B.x - A.x / 2
  Vektor.y = B.y - A.y / 2 (6)
- Rotate 90° degree counterclockwise
  *rad = 90 * (3.14 / 360)*
  *Rotate.x = (Vektor.x*cos(rad)) – (Vektor.y*sin(rad))*
  *Rotate.y = (Vektor.x*sin(rad)) – (Vektor.y*cos(rad))* (7)
- Create Perpendicular line
  tegaklurus.x = medPoint.x + Rotate.x
  tegaklurus.y = medPoint.y + Rotate.y (8)

The result of eq.(5) until eq.(8) only for 1 perpendicular line. To create several prependicular line along of shape we use iterate and loop until 20 as requirements of biplane disk summation. The result of prependicular along of line shown on Fig 9.



(a) (b)

Fig.9. Prependicular Line and Biplane result

F. Ejection Fraction

Ejection fraction(EF) is the percentage of blood that is ejected from the left ventricle during each heart beats to know how effectiveness of the heart function are[6]. It was calculated from different 4 image using diastole and systole image from AP4CH and AP2CH. The main of this method are left ventricle volume calculate from sum of elliptical disc[4]. The primary clinical method for calculating ventricular volumes to determine the EF uses the area-length formula shown in fig.12 has been recommended by *American Society of Echocardiography also European Association of Cardiovascular Imaging* [4].

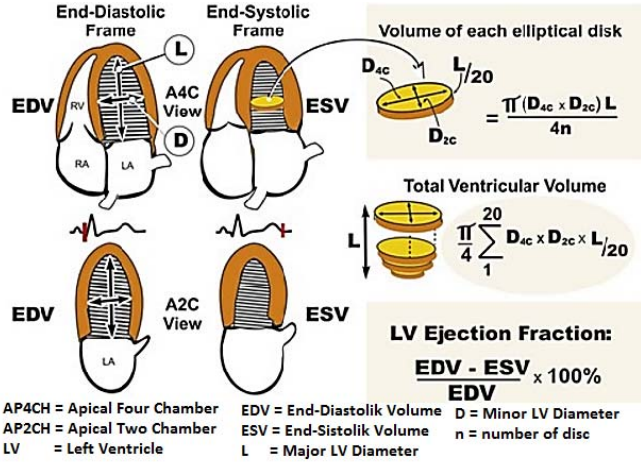


Fig.10. Ejection Fraction

IV. Experiment Result

We implemented optical flow to get the shape semi-automatically when systole and diastole phase. This method find the newest location while the heart move and reconstruct the shape using polyline. While marking the boundary of left ventricle, more than 20 points initialized in different location as feature to track. The picture on Fig.11 show how differ shapes between tracking and manual.

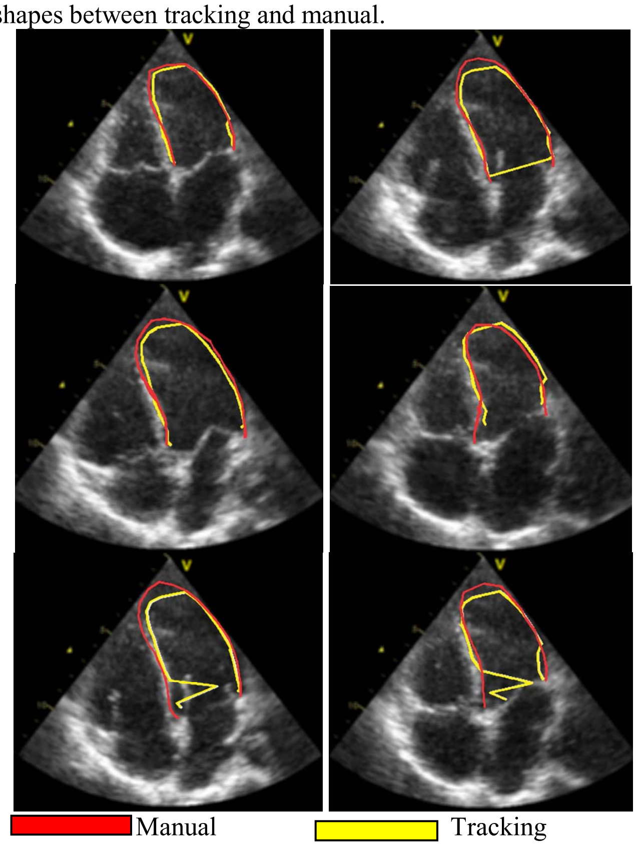


Fig.11. Comparison Shape between manual and tracking

The tracking result shown in Fig 12 on the 2 last picture, is getting bad because one feature move into muscle of left ventricle which have bigger movement. Also the shape looks rigid, because the characteristic of polyline only connecting each dots and there is no equation of quadratic to make the shape better.

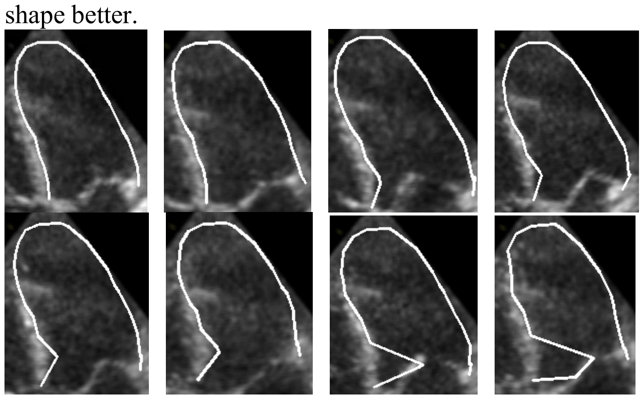


Fig.12. Tracking Result

After get the shape, next process is creating biplane to calculate the left ventricle volume. The biplane affected by the polyline result. On the Fig 13 shows there are 20 green lines called as elliptical discs. The number of lines are 20, it recommended by American Heart Association to calculate ejection fraction. It lines in the biplane disc suimmation method used to calculate distance between each walls.

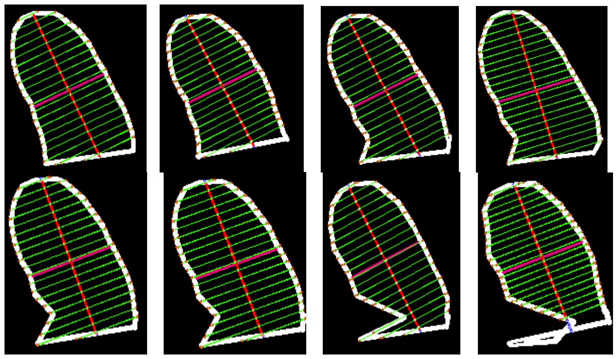


Fig.13. Biplane from Tracking

To know how optical flow improvement in ejection fraction measurement, we compare the shape's area resulted by system and user. Commonly doctor create the shape of systole and diastole phase by manually, but in this system we used the shapes by resulted optical flow tracking. The result shown on Table I, that there are 10 periode of heart cycle. One period contains systole and diastole shape. The method to calcluate area are uses sum of 40 green lines in every shape.

TABLE I. Results of area between system and user

No	Tracking (cm^2)	Manual (cm^2)	Error (%)
1	75.750	71.647	5.727
2	46.660	67.594	30.970
3	83.361	72.003	15.774
4	54.197	48.941	10.740
5	66.956	71.959	6.953
6	55.042	54.888	0.279
7	86.381	69.973	23.448
8	62.854	57.989	8.389

9	57.276	59.139	3.151
10	55.940	58.546	4.451
11	60.598	67.568	10.315
12	82.844	76.251	8.646
13	63.331	58.968	7.399
14	53.129	56.671	6.249
15	59.075	64.140	7.897
16	47.291	41.239	14.677
17	53.429	57.938	7.782
18	29.717	38.245	22.299
19	73.343	74.070	0.981
20	80.261	77.300	3.831
Average Error			9.998%

Based on Tabel 1, the average of differences area between user and system has 9.998%. It means that the result of optical flow movement can be used to reconstruct left ventricle's shape in systole and diastole phase semi-automatically. The shapes is very sensitive for the next step, we also compare the elliptical disc value between sistem and user result. We use 3 sample shape created by user which each of it has 18 green lines. In the Table II, error between system and user while diastole 10.43%, sistole 8.77%.

TABLE II. ELLIPTICAL DISC VALUE BETWEEN USER AND SYSTEM

No	Diastole (cm)		Sistole (cm)		Error (%)	
	AVE User	System	AVE User	System	Diastole	Sistole
1	1.49	1.96	1.38	1.79	23.97	22.71
2	3.12	2.87	2.82	3.38	8.94	16.568
3	3.86	3.73	3.41	3.91	3.57	12.70
4	4.44	4.38	3.68	4.27	1.44	13.66
5	4.72	4.74	4.11	4.52	0.42	9.07
6	4.96	5.11	4.54	4.97	2.80	8.65
7	4.99	5.07	4.74	4.89	1.44	2.99
8	5.35	4.99	4.67	5.17	7.28	9.60
9	5.43	5.19	4.82	5.12	4.75	5.72
10	5.53	5.04	4.95	5.05	9.72	1.91
11	5.52	5.24	4.88	4.84	5.34	-0.96
12	5.63	5.44	5.04	4.92	3.49	-2.57
13	5.82	5.77	4.94	4.89	0.92	-1.09
14	5.96	5.92	4.82	5.25	0.78	8.12
15	5.86	6.02	4.43	5.5	2.54	19.39
16	6.03	6	4.48	5.42	0.55	17.28
17	6.1	4.99	4.56	5.3	22.24	13.83
18	5.75	3.07	3.39	3.41	87.51	0.397
Average Error					10.43	8.77

In the table II, each of elliptical disc has different value, it will affect while measure ejection fraction. Ejection fraction calculate from percentage of comparison between end diastole volume (EDV) and end systole volume (ESV) of left ventricle in two Apical Four Chamber and Apical Two Chamber angle. So, it means EDV calculate sum of diastole elliptical disc value on Apical 2CH and Apical 4CH, meanwhile ESV systole elliptical disc. In table III, we compare between manual and tracking result to know the error and the differences. It can be seen average error of system and manual is 10.468%

TABLE III. EJECTION FRACTION VALUE BETWEEN TRACKING AND MANUAL

File	Manual(cm^2)	Tracking(cm^2)	Delta (cm^2)
Ang	28.770	16.330	12.44
Philipus	65.522	62.605	2.917
Rosidi	32.265	37.242	4.977
Abdul	34.310	42.413	8.103
Kodir	43.237	39.178	4.059
Jon	68.502	40.925	27.577
Dia	63.333	60.763	2.57
Lil	67.165	62.363	4.802
Sup	63.585	28.329	35.256
Mus	59.862	61.842	1.98
Average Error			10.468

V. CONCLUSION

Based on the experimental results, we conclude that the optical flow lucas-kanade method able to create the newest shape and get biplane automatically. The error of comparison shape's area between system and user around 9.998%. And elliptical disc value on biplane between user and system only 10.43% for diastole and 8.77% for sistole. The result of ejection fraction measurement using this system has error 10.468%. It shows that optical flow can improvement ejection fraction measurement which focus on reconstruct left ventricle's semi-automatically by using tracking result. So, doctor shouldn't create the shapes in systole and diastole phase manually.

VI. FUTURE WORK

In the future, we would like to improve shape which added the triangle equation to make shape better. And also more exploring in ejection fraction measurement.

VII. ACKNOWLEDGEMENT

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VIII. REFERENCES

[1] Hearts Technical Package For Cardiovascular Disease Management In Primary Health Care, World Health Organization Document; 2016

[2] J. Nonthaporn Nakphu, Dyah Ekashanti Octorina Dewi, "Apical Four-Chamber Echocardiography Segmentation using Marker-controlled Watershed Segmentation", IEEE Conference on Biomedical Engineering and Sciences, 8 - 10 December 2014, Miri, Sarawak, Malaysia;

[3] Dorin Comaniciu.Xiang Sean Zhou, "Robust Real-Time Myocardial Border Tracking for Echocardiography: An Information Fusion Approach", IEEE Transactions On Medical Imaging, Vol. 23, No. 7, July, 2004

[4] Roberto M. Lang, MD, FASE, FESC, Luigi P. Badano, MD, PhD, FESC; "GUIDELINES AND STANDARDS Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults", American Society of

Echocardiography and the European Association of Cardiovascular Imaging, America, 2005

[5] Sigurd Storve Jahn Frederik Grue,"Realtime Automatic Assessment of Cardiac Function in Echocardiography"; IEEE Transactions On Ultrasonics, Ferroelectrics, And Frequency Control, Vol. 63, No. 3, March; 2016

[6] Campion Quinn; 100 Questions & Answers About Congestive Heart Failure; Internist and Medical Consultant Rocville Center, New York; 2006

[7] John Kaplan; Kaplan's Cardiac Anesthesia; 2016

[8] R. E. Dwi, R. Sigit and Setiawardhana, "Semi-automatic border detection of cardiac cavity in echocardiography video," 2016 International Seminar on Intelligent Technology and Its Applications (ISITIA), Lombok, 2016, pp.169-174

[9] R. Sigit, M. M. Mustafa, A. Hussain, O. Maskon and I. F. M. Noh, "Automatic border detection of cardiac cavity images using boundary and triangle equation," TENCON 2009 - 2009 IEEE Region 10 Conference, Singapore, 2009, pp.144

[10] R.Sigit, T.Harsono and B.H.A.Noor, "Heart video tracking system on long axis view," 2016 International Electronics Symposium (IES), Denpasar, 2016, pp. 271-276.

[11] R. Sigit, A. R. Barakbah and I. A. Sulistijono, "Improved segmentation of cardiac image using triangle and partial Monte Carlo," 2016 International Conference on Knowledge Creation and Intelligent Computing (KCIC), Manado, 2016, pp 47-52

[12] R.Sigit and E.Rochmawati, "Segmentation echocardiography video using B-Spline and Optical Flow," 2016 International Konference on Knowledge Creation and Intelligent Computing (KCIC), Manado, 2016

[13] R.Sigit, "Segmentasiimeg untuk video ekokardiografi menggunakan persamaan segitiga". Fakulti Kejuteraan dan Alam Bina Universiti Kebangsaan Malaysia Bangi

[14] Kurniati, Neny; Basuki, Achmad; Pramadihanto, Dadet. Remo Dance Motion Estimation with Markerless Motion Capture Using The Optical Flow Method. EMITTER International Journal of Engineering Technology, [S.l.], v. 3, n. 1, mar. 2016

[15] Michael Bernier, Automatized Evaluation of the Left Ventricular Ejection Fraction from Echocardiographic Images Using Graph Cut; de l'Universit´e; 2015