Modified of Single Deepest Vertical Detection (SDVD) Algorithm for Amniotic Fluid Volume Classification

Putu Desiana Wulaning Ayu[1*], Gede Angga Pradipta[2],
Roy Rudolf Huizen[3], Kadek Eka Sapta W[4], I Gede Edy Artana[5]

[1,2,3]Department of Magister Information System, Institut Teknologi dan Bisnis STIKOM Bali, Indonesia
[4,5] Magister Program, Department of Magister Information System, Institut Teknologi dan Bisnis STIKOM Bali, Indonesia

*corr_author: wulaning_ayu@stikom-bali.ac.id

Abstract - Amniotic fluid a crucial role in ensuring the well-being of the fetus during pregnancy and is contained within the amnion cavity, which is surrounded by a membrane. Several studies have shown that volume of amniotic fluid can vary throughout pregnancy and is closely linked to the health and safety of the fetus. This indicates that it is essential to perform accurate measurement and identification of its volume. Obstetric specialist often use a manual method to identify amniotic fluid by visually determining the longest straight vertical line between the upper and lower boundaries. Therefore, this study aims to develop detection model, known as modified Single Deepest Vertical Detection (SDVD) algorithm to automatically measure the longest vertical line by following medical rules and regulations. SDVD algorithm was designed to measure the depth of amniotic fluid vertically by searching the column of pixels that comprised the image sample, excluding any intersection with the fetal body. Performance testing was carried out using 130 images by comparing the manual measurement results obtained by obstetric specialists and the proposed model. Based on the experimental results using modified SDVD, the average accuracy, precision, and recall achieved for amniotic fluid classification were 92.63%, 85.23%, and 95.6%, respectively.

Keywords: amniotic fluid, volume, modified SDVD, classification

I. INTRODUCTION

Amniotic fluid is contained within the amnion cavity, which is enveloped by a protective membrane. The formation of the amnion cavity typically commences between days 10 and 20 after fertilization [1]. Furthermore, the primary function of amniotic fluid is to shield the developing fetus from potential impacts against the uterine wall and to safeguard the umbilical cord from exerted pressure [2][3]. Several studies have shown that its volume gradually increases throughout the course of pregnancy. At 12 weeks, it measures approximately 50 ml, which increases to 350-400 ml at 20 weeks, and 1000 ml at 35-38 weeks [4]. Based on previous reports, there is often a significant surge in amniotic fluid volume from weeks 8 to 28. After the 28th week, the increment rate typically diminishes, stabilizing at around 35-36 weeks. As the pregnancy progresses beyond 41 weeks (post-term), volume starts to decline, occasionally dropping below 500 ml [5].

Obstetric specialists often employ a medical technique known as Single Deepest Pocket (SDP) to assess volume of amniotic fluid [6]. SDP classifies volume into 3 categories, namely Oligohydramnios, Polyhydramnios, and Normal characterized by the longest vertical line measuring <2 cm, ≥8 cm, and 2-8 cm, respectively [7][8]. The process commences by identifying and determining the largest single pocket of amniotic fluid during the examination, ensuring it is not obstructed by the umbilical cord and fetal body. Calipers are then positioned at the upper (adjacent to the placenta) and lower (adjacent to the uterus) boundaries of the largest single pocket of amniotic fluid. Subsequently, the longest vertical line between these calipers is drawn without contacting the fetal body or other objects [9]. This procedure, known as the Maxima Vertical Pocket (MVP) method, is employed to draw the longest vertical line [10]. The subsequent step involves measuring the length to categorize amniotic fluid volume. The ultrasound monitor screen displays calipers as measurement markers. The calipers and other parts of amniotic fluid image are presented in Fig.1.

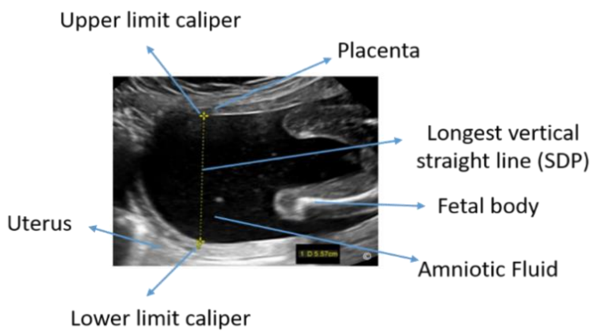


Fig. 1 Parts of amniotic fluid image [11]

One limitation of the manual volume measurement conducted by obstetric specialists is the potential of the drawn line between the two calipers to deviate from perfect vertical alignment, which can affect the diagnosis of amniotic fluid based on volume. Therefore, this study proposes the development of detection model, known as modified Single Deepest Vertical Detection (SDVD) algorithm. The primary aim of modified SDVD algorithm is to automatically measure the longest vertical line within the region of interest (ROI) of amniotic fluid in accordance with medical rules and regulations. The ROI is a binary image, where the white color (1) represents amniotic fluid, while the black color (0) indicates other organs. Algorithm searches the columns of pixels comprising the image to obtain vertical line that does not intersect with the fetal body. This ensures that the detected vertical line accurately reflects amniotic fluid volume.

Several studies have utilized various methods to determine amniotic volume, including SDP [12]. This approach utilizes opening and closing methods within the ROI. The opening aims to eliminate small positive holes, while the closing fills small holes to obtain deepest vertical length. Furthermore, our previous researh [13][14] developed a calculation model that identified the column in the matrix with the highest number of 1 (white), representing amniotic fluid. The output of this algorithm is the number of pixels in the column with the highest number of 1, as well as its corresponding index. Several studies have successfully represented the length of the longest vertical line but the problem of intersecting lines caused by the fetal body has not been addressed. Therefore, the novelty of this study lies in the Development Model of modified SDVD algorithm, which aims to measure the depth of amniotic fluid vertically. Algorithm searches the columns of pixels constituting the image, specifically targeting those that do not intersect with the fetal body. Based on the experimental results using modified SDVD, show SDP/vertical length measurement results of amniotic fluid on the testing data had an absolute difference closeness of 86.86% or an absolute average error rate of 13.14%. The remaining part of this study is organized as follows: Section 2 explains the methods used, while Section 3 focuses on the experimental results and analysis. Section 4 elaborates on the conclusion of the study.

II. METHOD

This study proposed a model for measuring amniotic fluid volume using modified SDVD algorithm approach on 2D ultrasound images. Modified SDVD algorithm aimed to obtain the longest straight vertical line without any intersections or contact with other objects, such as the umbilical cord, bones, or fetal body parts. Furthermore, the development model for measuring amniotic fluid volume consisted of 4 stages, as shown in Fig. 2. The model began with image acquisition and pre-processing, followed by the determination of volume using modified SDVD algorithm. The next stage involved calibration from pixels to centimeters and the last stage was to compare measurement results produced by the proposed method (SDVD algorithm) with those obtained by obstetric specialists.This section generally consists of types of research, research objects, time of research, data collection, data analysis methods, ways of presenting analysis results, and data validity. These sections are tentative and adapted to the type of research. The flow or research steps are better presented as flowcharts to facilitate understanding the research steps being carried out.

A. Image Acquisition and Pre-Processing

B-mode ultrasound amniotic fluid images were recorded using an ultrasound machine. A total of 130 image samples were used, of which 95 and 40 were employed for training and testing, respectively[13], [15], [16]. Amniotic fluid images were obtained from the Obstetrics and Gynaecology laboratory of Surya Husadha Hospital in Bali. Furthermore, the specifications of the machine used included Accuvix XG and transducer with 3.5 Hz frequency, 3-0.2 mm lateral resolution, jpg image format, and 800 x 600 pixels size[15], [16]. The gestational age of the included data was in the second trimester during the 13th week, and obese pregnant women were excluded. The pre-processing process was carried out by segmenting the AF image using the U-Net semantic segmentation model approach with the Roonerberger architecture [16]- [19].

B. Modified SDVD Algorithm

To determine amniotic fluid volume using an ultrasound machine, the obstetrician drew the calipers vertically. Furthermore, the calipers were placed and drawn vertically after identifying amniotic fluid area that was free from the fetal body and umbilical cord. To obtain SDP measurement that aligned with the medical guidelines in obstetrics and gynecology, this study proposed algorithm to achieve the longest straight vertical line (modified SDVD) within the ROI of amniotic fluid, as shown in Fig. 3. The ROI was a binary image where the white color (1) represented amniotic fluid, while the black color (0) indicated other organs. The medical SDP method stated that the longest straight vertical line must not have any intersections or contact with other objects [10]. The steps of this algorithm are presented below:

- The first step was to create a bounding box around the ROI of amniotic fluid, where *m* and *n* represented the window size.
- The next step was to initialize the parameter *k* for column iteration. The *flag* was a parameter used to check for the presence of other organs in column *k*, indicated by the black color (0). When black (0) was encountered, the row in the window (*n*) could not be used to obtain the longest straight vertical line and algorithm moved to the next column (*m*), where b was the iteration for rows. Furthermore, *Sum* was used to store the count of white pixels in a row and *Max* was used to store the maximum count of white pixels in a column.
- The iteration started from the first column and the check was performed to determine whether the iteration of column (*k*) was ≤*m*. If the iteration was still within the column below the value of *m*, it proceeded to row *b* until *b*≤*n*. Each value of 1 with a *flag* value less than 2 was considered a white pixel contributing to the longest straight vertical line. The *flag* value changed to 2 when there was a transition from a value of 1 to 0. The result of this algorithm formed the white pixels (1), thereby automatically obtaining the longest straight vertical line. Meanwhile, to obtain measurement in centimeters for the longest straight vertical line, the pixel conversion process was performed as described in section.

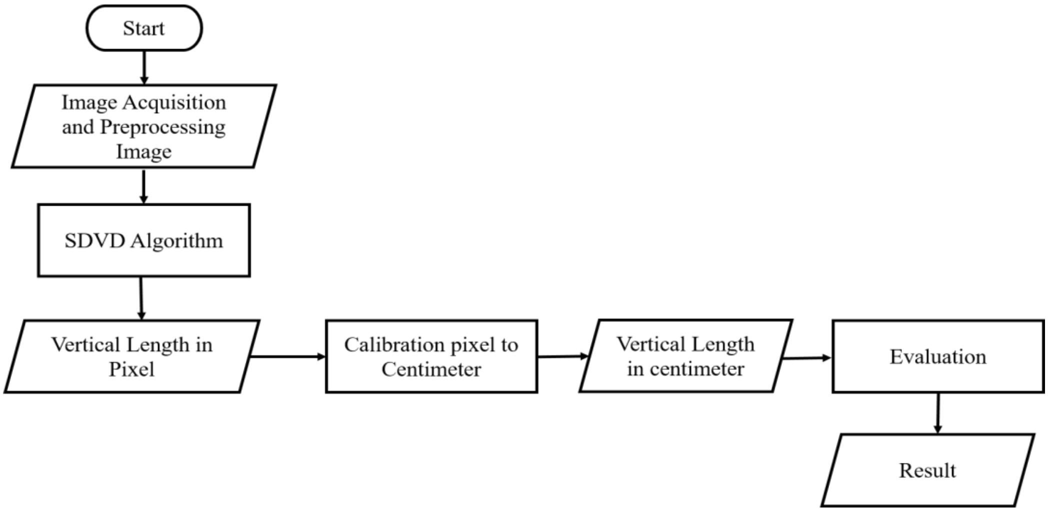


Fig. 2 The development model for measuring amniotic fluid volume

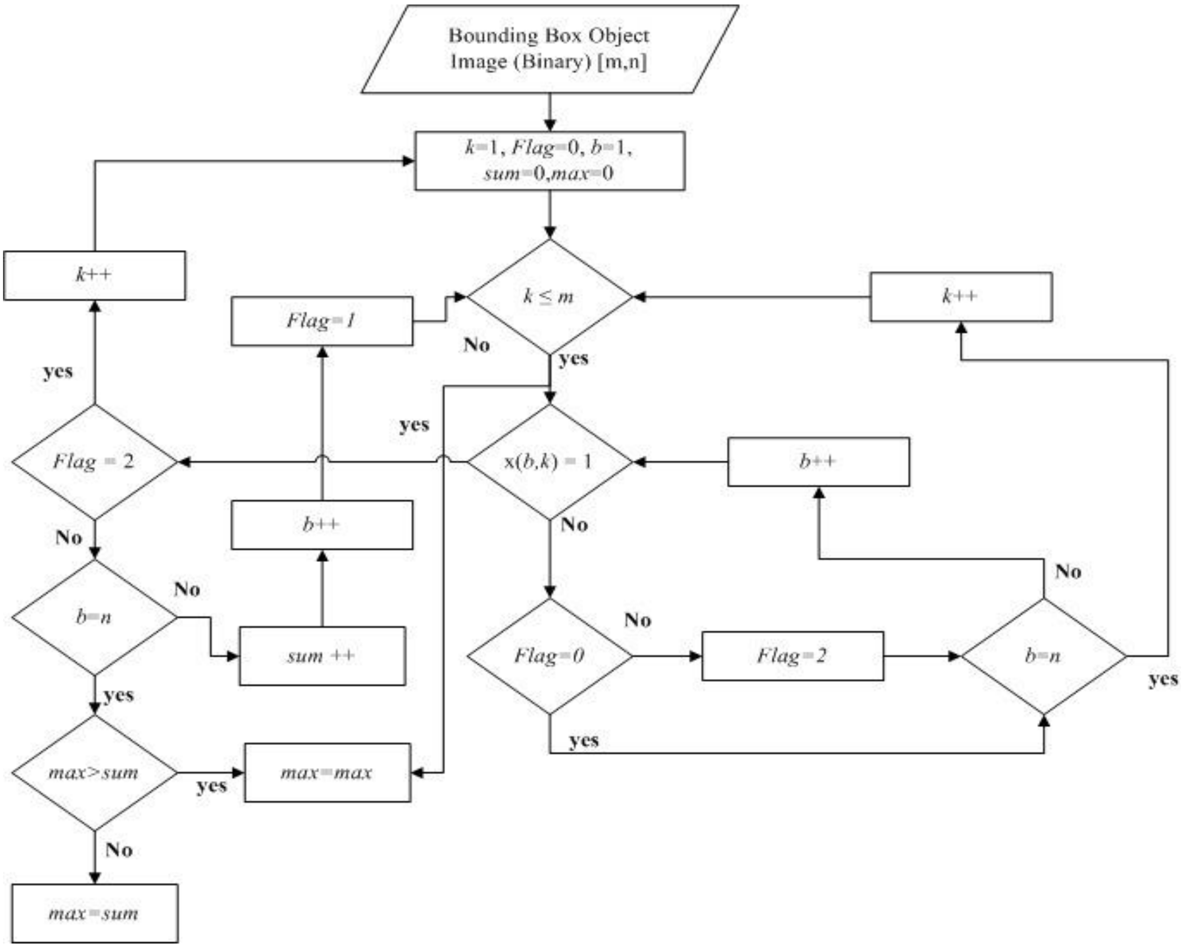


Fig. 3 Flowchart of the proposed modified SDVD algorithm

C. Pixel to Centimeter Calibration

The calibration process from pixels to centimeters (cm) in amniotic fluid ultrasound image was carried out using a reference line (vertical) or strip in the right-side information area. The distance between these 2 points or lines/strips represented the value of 1 centimeter (cm), which was obtained from the information provided in the ultrasound image. The value of 1 centimeter (cm) consisted of 28 pixels, determined by summing the number of pixels. To create this line, the imline function in Matlab was used, which interactively placed a line on the desired pixel axis or coordinates in the image. The imline function generated the coordinates from the starting point and endpoint of the drawn line. Furthermore, to determine the distance between these points, the Euclidean distance calculation was used. The results showed the distance in terms of the number of pixels constituting the length of the line. In this study, the starting and endpoint coordinates used for calibration were 621,147 and 621,175, respectively. From these coordinates, the constituent pixels were then calculated.

Based on the calculation results, the distance or number of pixels between these 2 points was 28 pixels, which was stored in the variable *d*. Therefore, the calibration process from pixels to centimeters yielded$\frac{1}{28} = 0{,}0357\ cm$, stored in the variable pixel_size.

D. IF-THEN Algorithm

The testing scheme for amniotic fluid volume classification model was divided into 2 two parts, namely training and testing data. Classification of amniotic fluid volume was carried out by forming rules in the form of IF-THEN. SDVD value served as a reference to determine the class of the input image. An SDVD value of <2.0, ≥8.0, and 2-8 cm belonged to the Oligohydramnios, Polyhydramnios, and Normal classes, respectively. The performance of amniotic fluid volume classification was divided into 3 classes (Normal, Oligohydramnios, and Polyhydramnios) and was evaluated using a multiclass confusion matrix.

E. Performance Evaluation

To assess the performance of SDVD algorithm, a comparison was made between SDP measurement results obtained from obstetric specialists and the proposed method. The experiment was conducted on 40 amniotic fluid testing images and the unit of length was centimeters (cm). Meanwhile, the parameters used to evaluate the performance of amniotic fluid volume classification included accuracy, precision, and recall, as indicated in equations (1-3) [20].

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

TP is True Positive (a positive label predicted as an actual label), FP is False Positive (negative label but predicted as a positive label), TN is True Negative (negative data predicted correctly), and FN is False Negative (a positive label but predicted as a negative label).

III. RESULT AND DISCUSSION

Tests were carried out using 3 scenarios, where the first was to test and see the performance of the proposed method on the classification of amniotic fluid volume in the training dataset. The second scenario is to test the classification of the test dataset the third scenario is to compare the proposed method with the previous study.

A. Performance Results of Modified SDVD for Amniotic Fluid Volume on Training Data

Table I presented a comparison of several examples of amniotic fluid volume classification results on the training data. The results showed 7 out of 95 images had different classification compared to the ground truth labels, namely AF65, AF66, AF77, AF81, AF86, AF89, and AF93. The differences in volume classification results were attributed to poor segmentation outcomes in these images. This was caused by the presence of significant redundancy between amniotic fluid and the ultrasound wave reflections on the uterine wall, leading to the formation of black areas with a similar appearance to amniotic fluid. Table II shows the multiclass confusion matrix for amniotic fluid volume on training data.

Based on Table II, classification model for measuring SDP on training data had 92.63% accuracy, 85.23% precision, and 95.60% recall.

B. Performance Results of Modified SDVD for Amniotic Fluid Volume on Testing Data

In this section, a comparison testing was conducted between amniotic fluid SDP measurement made by obstetric specialists and the proposed method (SVDD). This was performed to determine the absolute difference closeness between the 2 measurements. Furthermore, the experiment was performed on 40 testing images and the results are shown in Table III.

SDP measurement results of amniotic fluid from the proposed modified SDVD method on the testing data had an absolute difference closeness of 86.86% or an absolute average error rate of 13.14%. The results of the liquid volume classification on the testing data with a total of 40 images are shown in Table IV.

The testing was conducted using 40 images that contained SDP information obtained from the obstetric specialists' measurement. According to Table 4, a total of 4 out of the 40 images had different classification results compared to the obstetric specialists' labels, namely AFU08, AFU13, AFU15, and AFU39. Furthermore, the multiclass confusion matrix for the testing data was presented in Table V.

Based on Table V, the performance of the model using the IF-THEN algorithm and the proposed method (SDVD) in classifying amniotic fluid volume in the testing data showed 90% accuracy, 80% precision, and 92% recall. The results shown by the multiclass confusion matrix in Tables 2 and 5 for amniotic fluid classification using the IF-THEN algorithm demonstrated good performance on both training and testing data. Furthermore, Fig. 4 presented vertical length measurement results using the proposed SDVD algorithm method.

TABLE I
CLASSIFICATION RESULTS OF AMNIOTIC FLUID VOLUME BETWEEN THE LABEL AND THE PROPOSED METHOD OR SYSTEM ON TRAINING DATA

Image Name	Classification of Amniotic Fluid Volume from Obstetric specialists' Label	Classification of Amniotic Fluid Volume from the Proposed Model	Image Name	Classification of Amniotic Fluid Volume from Obstetric specialists' Label	Classification of Amniotic Fluid Volume from the Proposed Model
AF01	Normal	Normal	AF49	Normal	Normal
AF02	Normal	Normal	AF50	Normal	Normal
AF03	Normal	Normal	AF51	Normal	Normal
AF04	Normal	Normal	AF52	Normal	Normal
AF05	Normal	Normal	AF53	Normal	Normal
AF06	Normal	Normal	AF54	Normal	Normal
AF07	Normal	Normal	AF55	Normal	Normal
AF08	Normal	Normal	AF56	Normal	Normal
AF09	Normal	Normal	AF57	Normal	Normal
AF10	Normal	Normal	AF58	Normal	Normal
AF11	Normal	Normal	AF59	Normal	Normal
AF12	Normal	Normal	AF60	Normal	Normal
AF13	Normal	Normal	AF61	Normal	Normal
AF14	Normal	Normal	AF62	Oligohydramnion	Oligohydramnion
AF15	Normal	Normal	AF63	Oligohydramnion	Oligohydramnion
AF16	Normal	Normal	AF64	Oligohydramnion	Oligohydramnion
AF17	Normal	Normal	AF65	Oligohydramnion	Normal
AF18	Normal	Normal	AF66	Oligohydramnion	Normal
AF19	Normal	Normal	AF67	Oligohydramnion	Oligohydramnion
AF20	Normal	Normal	AF68	Oligohydramnion	Oligohydramnion
AF21	Normal	Normal	AF69	Oligohydramnion	Oligohydramnion
AF22	Normal	Normal	AF70	Polihidramnion	Polihidramnion
AF23	Normal	Normal	AF71	Polihidramnion	Polihidramnion
AF24	Normal	Normal	AF72	Polihidramnion	Polihidramnion
AF25	Normal	Normal	AF73	Polihidramnion	Polihidramnion
AF26	Normal	Normal	AF74	Polihidramnion	Polihidramnion
AF27	Normal	Normal	AF75	Polihidramnion	Polihidramnion
AF28	Normal	Normal	AF76	Polihidramnion	Polihidramnion
AF29	Normal	Normal	AF77	Polihidramnion	Normal
AF30	Normal	Normal	AF78	Polihidramnion	Polihidramnion
AF31	Normal	Normal	AF79	Polihidramnion	Polihidramnion
AF32	Normal	Normal	AF80	Polihidramnion	Polihidramnion
AF33	Normal	Normal	AF81	Polihidramnion	Normal
AF34	Normal	Normal	AF82	Polihidramnion	Polihidramnion
AF35	Normal	Normal	AF83	Polihidramnion	Polihidramnion
AF36	Normal	Normal	AF84	Polihidramnion	Polihidramnion
AF37	Normal	Normal	AF85	Polihidramnion	Polihidramnion
AF38	Normal	Normal	AF86	Polihidramnion	Normal
AF39	Normal	Normal	AF87	Polihidramnion	Polihidramnion
AF40	Normal	Normal	AF88	Polihidramnion	Polihidramnion
AF41	Normal	Normal	AF89	Polihidramnion	Normal
AF42	Normal	Normal	AF90	Polihidramnion	Polihidramnion
AF43	Normal	Normal	AF91	Polihidramnion	Polihidramnion
AF44	Normal	Normal	AF92	Polihidramnion	Polihidramnion
AF45	Normal	Normal	AF93	Polihidramnion	Normal
AF46	Normal	Normal	AF94	Polihidramnion	Polihidramnion
AF47	Normal	Normal	AF95	Polihidramnion	Polihidramnion
AF48	Normal	Normal			

TABLE II
MULTICLASS CONFUSION MATRIX FOR AMNIOTIC FLUID VOLUME ON TRAINING DATA

Confusion matrix for amniotic fluid volume		Label: Normal	Label: Oligo	Label: Poli	Total
Model classification results	Normal	61	2	5	68
	Oligo	0	6	0	6
	Poli	0	0	21	21
	Total	61	8	26	95

**oligo: Oligohydramnion, Poli: Polihidramnion*

TABLE III
PERFORMANCE RESULTS OF SDP MEASUREMENT COMPARISON ON TESTING DATA

Image name	Obstetric specialists' measurement (cm)	Measurement of the proposed model (cm)	Difference (cm)
AFU01	3.36	3.85	0.49
AFU02	4.55	4.53	0.021
AFU03	5.65	4.71	0.94
AFU04	4.22	3.78	0.44
AFU05	5.69	5.96	0.27
AFU06	4.18	4.42	0.24
AFU07	7.53	7.71	0.18
AFU08	7.69	9.21	1.52
AFU09	10.54	11.75	1.21
AFU10	11.82	8.07	3.75
AFU11	8.09	9.64	1.55
AFU12	13.37	15.35	1.98
AFU13	5.86	8.53	2.67
AFU14	8.71	8.82	0.11
AFU15	7.00	9.00	2.00
AFU16	8.21	9.57	1.36
AFU17	8.97	9.92	0.95
AFU18	4.85	5.85	1.00
AFU19	5.05	3.85	1.19
AFU20	6.18	5.85	0.32

Image name	Obstetric specialists' measurement (cm)	Measurement of the proposed model (cm)	Difference (cm)
AFU21	6.68	5.67	1.00
AFU22	5.79	7.07	1.28
AFU23	4.58	5.17	0.59
AFU24	6.63	6.32	0.31
AFU25	5.20	5.39	0.19
AFU26	4.25	4.07	0.17
AFU27	5.08	5.28	0.20
AFU28	3.96	3.39	0.57
AFU29	6.06	5.28	0.77
AFU30	5.38	5.00	0.38
AFU31	6.68	6.10	0.58
AFU32	4.46	3.85	0.60
AFU33	7.50	7.39	0.10
AFU34	5.15	4.60	0.54
AFU35	5.23	5.82	0.59
AFU36	6.32	6.25	0.07
AFU37	5.52	6.25	0.73
AFU38	4.40	5.71	1.31
AFU39	7.66	8.57	0.91
AFU40	2.14	1.71	0.42

TABLE IV
COMPARISON RESULTS OF AMNIOTIC FLUID VOLUME CLASSIFICATION BETWEEN THE OBSTETRIC SPECIALISTS' LABEL AND THE PROPOSED METHOD (SDVD)

Image Name	Classification of Amniotic Fluid Volume from Obstetric specialists' Label	Classification of Amniotic Fluid Volume from the Proposed Model	Image Name	Classification of Amniotic Fluid Volume from Obstetric specialists' Label	Classification of Amniotic Fluid Volume from the Proposed Model
AFU01	Normal	Normal	AFU21	Normal	Normal
AFU02	Normal	Normal	AFU22	Normal	Normal
AFU03	Normal	Normal	AFU23	Normal	Normal
AFU 04	Normal	Normal	AFU24	Normal	Normal
AFU 05	Normal	Normal	AFU25	Normal	Normal
AFU 06	Normal	Normal	AFU26	Normal	Normal
AFU 07	Normal	Normal	AFU27	Normal	Normal
AFU 08	Normal	Polihidramnion	AFU28	Normal	Normal
AFU09	Polihidramnion	Polihidramnion	AFU29	Normal	Normal
AFU10	Polihidramnion	Polihidramnion	AFU30	Normal	Normal
AFU11	Polihidramnion	Polihidramnion	AFU31	Normal	Normal
AFU12	Polihidramnion	Polihidramnion	AFU32	Normal	Normal
AFU13	Normal	Polihidramnion	AFU33	Normal	Normal
AFU14	Polihidramnion	Polihidramnion	AFU34	Normal	Normal
AFU15	Normal	Polihidramnion	AFU35	Normal	Normal
AFU16	Polihidramnion	Polihidramnion	AFU36	Normal	Normal
AFU17	Polihidramnion	Polihidramnion	AFU37	Normal	Normal
AFU18	Normal	Normal	AFU38	Normal	Normal
AFU19	Normal	Normal	AFU39	Normal	Polihidramnion
AFU20	Normal	Normal	AFU40	Oligohydramnion	Oligohydramnion

TABLE V
MULTICLASS CONFUSION MATRIX FOR AMNIOTIC FLUID VOLUME ON TESTING DATA

Confusion matrix for amniotic fluid volume		Label			Total
		Normal	Oligo	Poli	
Model classification results	Normal	28	0	4	32
	Oligo	0	1	0	1
	Poli	0	0	7	7
	Total	28	1	11	40

**Oligo: Oligohydramnion, Poli: Polihidramnion*

Fig. 4 on the red line in parts (c) and (d) showed measurement results of vertical length with the proposed modified SDVD algorithm method.

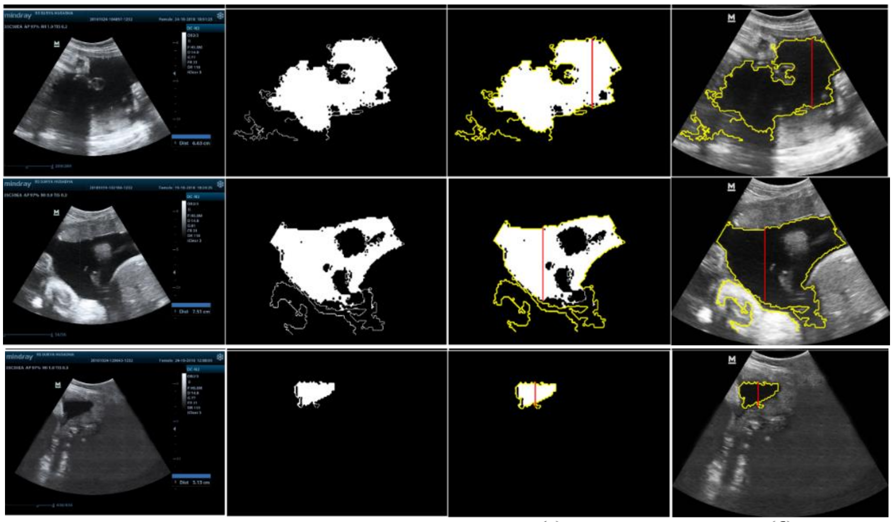
C. Performance Result of Modified SDVD on Previous Study

This section presented a comparison of the performance between the proposed method and previous studies on classification of amniotic fluid volume, as shown in Table VI.

Based on Table VI, the proposed method experienced an improvement in performance, namely a 9%, 4%, and 13% increment in accuracy, precision, and recall, respectively.

TABLE VI
COMPARISON OF PERFORMANCE BETWEEN THE PROPOSED METHOD AND PREVIOUS STUDIES

Study/Research	Accuracy	Precision	Recall
Training Data (proposed method)	92.63%	85.23%	95.60%
Testing Data (proposed method)	90%	80%	90%
Previous method [13]	81%	80.4%	81%



(a) (b) (c) (d)

Fig. 4 SDP measurement results using the proposed method (a) original image, (b) segmentation result, (c) segmentation image with vertical length, (d) segmentation result and SDVD algorithm

IV. CONCLUSION

In conclusion, the manual measurement by obstetric specialists posed a challenge as the drawn line between the two calipers was not perfectly vertical, potentially affecting the diagnosis of amniotic fluid based on volume. Therefore, this study developed detection model to automatically measure the longest straight vertical line following the medical rules and guidelines, known as modified SDVD algorithm. SDVD algorithm aimed to find the longest and straight vertical line within the ROI of amniotic fluid. The ROI was a binary image where white color (1) represented amniotic fluid, while black color (0) indicated other organs. Algorithm used searched for columns of pixels making up the image that does not intersect with the fetal body, hence, the formed vertical line truly represented amniotic fluid volume. Based on experimental results using modified SDVD algorithm, the average accuracy, precision, and recall achieved for amniotic fluid classification were 92.63%, 85.23%, and 95.6%, respectively.

ACKNOWLEDGEMENT

The authors are grateful to the Directorate of Research, Technology, and Community Service (DPRM) Indonesia for funding this study through Program Funding (DRPM) for the 2023 Fiscal Year.

REFERENCES

[1] S. Posh, S. Rafiq, M. Dar, R. Aslam, and S. Bhat, “Role of amniotic fluid echogenicities in the prediction of fetal outcome,” *J. Sci. Soc.*, vol. 47, no. 1, p. 33, 2020, doi: https://doi.org/10.4103/jss.jss_9_20.

[2] W. Dc and L. Rock, “Dubil2013,” vol. 16, no. May, 2013.

[3] X. L. Tong, L. Wang, T. B. Gao, Y. G. Qin, Y. Q. Qi, and Y. P. Xu, “Potential function of amniotic fluid in fetal development-novel insights by comparing the composition of human amniotic fluid with umbilical cord and maternal serum at mid and late gestation,” *J. Chinese Med. Assoc.*, vol. 72, no. 7, pp. 368–373, 2009, doi:https://doi.org/10.1016/S1726-4901(09)70389-2.

[4] G. Tam and T. Al-Dughaishi, “Case report and literature review of very echogenic amniotic fluid at term and its clinical significance,” *Oman Med. J.*, vol. 28, no. 6, pp. 28–30, 2013, doi: https://doi.org/10.5001/omj.2013.129.

[5] L. Dallaire and M. Potier, “Amniotic fluid,” *Encyclopedia of Reproduction*, vol. 3. Elsevier, pp. 53–97, 2012.

[6] A. F. Nabhan and Y. A. Abdelmoula, “Amniotic fluid index versus single deepest vertical pocket: a meta-analysis of randomized controlled trials,” *J. Gynecol. Obstet.*, vol. 104, no. 3, pp. 184–188, 2009, doi: https://doi.org/10.1016/j.ijgo.2008.10.018.

[7] M. H. Beall, J. P. H. M. van den Wijngaard, M. J. C. van Gemert, and M. G. Ross, “Amniotic Fluid Water Dynamics,” *Placenta*, vol. 28, no. 8–9, pp. 816–823, 2007, doi: https://doi.org/10.1016/j.placenta.2006.11.009.

[8] M. I. Martínez-León, “Fetal imaging,” *J. Ultrasound Med.*, vol. 33, no. 5, pp. 745–757, 2014.

[9] S. Kehl, A. Schelkle, A. Thomas, A. Puhl, K. Meqdad, B. Tuschy, S. Berlit, C. Weiss, C. Bayer, J. Heimrich, U., “Single deepest vertical pocket or amniotic fluid index as evaluation test for predicting adverse pregnancy outcome (SAFE trial): A multicenter, open-label, randomized

controlled trial," *Ultrasound Obstet. Gynecol.*, vol. 47, no. 6, pp. 674–679, 2016, doi: https://doi.org/10.1002/uog.14924.

[10] S. Q. Rashid, "Amniotic fluid volume assessment using the single deepest pocket technique in bangladesh," *J. Med. Ultrasound*, vol. 21, no. 4, pp. 202–206, 2013, doi: https://doi.org/10.1016/j.jmu.2013.10.011.

[11] P. D. W. Ayu, S. Hartati, A. Musdholifah, and D. S. Nurdiati, "Amniotic fluid segmentation based on pixel classification using local window information and distance angle pixel," *Appl. Soft Comput.*, vol. 107, 2021, doi: https://doi.org/10.1016/j.asoc.2021.107196.

[12] H.C. Cho, S. Sun, C. Min Hyun, J.Y. Kwon, B. Kim, Y. Park, J.K. Seo, "Automated ultrasound assessment of amniotic fluid index using deep learning," *Med. Image Anal.*, vol. 69, p. 101951, 2021, doi: doi.org/10.1016/j.media.2020.101951, doi: https://doi.org/10.1016/j.media.2020.101951.

[13] P. D. W. Ayu, S. Hartati, A. Musdholifah, and D. S. Nurdiati, "Amniotic fluid classification based on volume and echogenicity using single deep pocket and texture feature," *ICIC Express Lett.*, vol. 15, no. 7, pp. 681–691, 2021, doi: https://doi.org/10.24507/icicel.15.07.681.

[14] D. S. N. Ayu, P D W, Sri hartati, Aina Musdholifah, "Amniotic Fluids Classification Using Combination of Rules-Based and Random Forest Algorithm," in *Soft Computing in Data Science*, 2022, p. 15, doi: https://doi.org/https://doi.org/10.1007/978-981-16-7334-4_20.

[15] P. D. W. Ayu, S. Hartati, A. Musdholifah, and D. S. Nurdiati, "Amniotic fluid segmentation based on pixel classification using local window information and distance angle pixel," *Appl. Soft Comput.*, vol. 107, p. 107196, 2021, doi: https://doi.org/10.1016/j.asoc.2021.107196.

[16] P. D. Wulaning Ayu and G. A. Pradipta, "U-Net Tuning Hyperparameter for Segmentation in Amniotic Fluid Ultrasonography Image," *2022 4th Int. Conf. Cybern. Intell. Syst. ICORIS 2022*, 2022, doi: https://doi.org/10.1109/ICORIS56080.2022.10031294.

[17] O. Ronneberger, P. Fischer, and T. Brox, "U-net: convolutional networks for biomedical image segmentation," *Lect. Notes Comput. Sci.*, vol. 9351, pp. 234–241, 2015, doi: https://doi.org/10.1007/978-3-319-24574-4_28.

[18] M. Han, Y. Bao, Z. Sun, S. Wen, L. Xia, J. Zhao, J. Du, Z. Yan, "Automatic segmentation of human placenta images with u-net," *J. IEEE Access*, vol. 7, pp. 180083–180092, 2019, doi: https://doi.org/10.1109/ACCESS.2019.2958133.

[19] K. bing Chen, Y. Xuan, A. jun Lin, and S. hua Guo, "Lung computed tomography image segmentation based on U-Net network fused with dilated convolution," *Comput. Methods Programs Biomed.*, vol. 207, p. 106170, Aug. 2021, doi: https://doi.org/10.1016/J.CMPB.2021.106170.

[20] P. D. W. Ayu and S. Hartati, "Pixel Classification Based on Local Gray Level Rectangle Window Sampling for Amniotic Fluid Segmentation," *Int. J. Intell. Eng. Syst.*, vol. 14, no. 1, pp. 420–432, 2021, doi: https://doi.org/10.22266/IJIES2021.0228.39.