Automatic Gestational Age Estimation Based on Crown Rump Length and Gestational Sac

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***Abstract*—The development of ultrasound technology allows us to see the structure and development of the fetus directly. Crown-Rump Length (CRL) and mean diameter of gestational sac (MSD) can be used to determine the age of the fetus. Both parameters are useful for measuring different aspects of the first trimester of pregnancy. This study proposes a method to obtain those parameter values automatically by converting the number pixels of ultrasound image into measurement unit. Image processing method is used to separate fetal object and gestational sac from other objects based on their boundaries. On this primary study, successive calculation of CRL and MSD using the proposed method is 60% and 70% respectively by 10 sample ultrasound images. Future expectations, these basic and other findings can be better developed to help midwives and general practitioners using ultrasound easier.**

***Index Terms*—automation, boundary detection, crown-rump length, gestational sac diameter, ultrasound**

I. Introduction

Determination of fetal age is the primary screening to determine the birth date, whether premature, normal, or post-dates deliveries [1]. Ultrasound is a common tool to monitor fetal development. In the first-trimester, Crown-Rump Length (CRL) and Mean Sac Diameter (MSD) are the recommended parameter for gestational age compared to Bi-Parietal Diameter (BPD) or other methods [2]. Ultrasound is widely used during pregnancy due to relatively low prices and trusted safe for the fetus health [3]. However, this tool has several weaknesses, such the image is not very clear results compared with other modalities [4]. Users should be expert in order to determine fetal CRL or Mean Sac Diameter (MSD) accurately. To overcome such weaknesses, image-processing aid can be used.

This process has its own advantages. Ultrasound image can be manipulated to produce understandable information for computers regarding to fetal object, fetal area, fetal border, and fetal length, as well as sac area, sac border, and sac length.

Despite the method has not conducted feasibility test by medical experts, in the future, the development of this research may be useful for a midwife or other users who are not ultrasound experts.

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II. Basic Theories and Methods

CRL is recognized and very useful for measuring early pregnancies, especially in the first trimester. CRL highly productive and is the most accurate measurement for gestational age. From 6 weeks to age 9 1/2 weeks of gestation, fetal CRL grow at a rate of about 1 mm per day. After 12 weeks, CRL gestational age accuracy is reduced and replaced by measurement of BPD. The CRL chart of gestational is obtained from the average of three measurements compares 5-12 weeks of CRL as shown in Fig. 1. CRL calculation is as follows. Gestational age is equal to 6 weeks plus (CRL × days). It depends on the growth of normal fetal 1 mm per day after 6 weeks of pregnancy [5]. For example, the CRL of 16 mm will be in accordance with the gestational age of 8 weeks and two days (6 weeks plus 16 days = 8 weeks and 2 days).

Gestational sac is the first sign of early pregnancy. It can be seen with ultrasound endovaginal around 3-5 weeks of pregnancy when the MSD of 2-3mm. It can effectively estimate the gestational age between 5 to 6 weeks using abdominal ultrasound with approximately about ± 5 days [6]. The precision of the measurement of the gestational sac as a predictor of gestational age was evaluated in the report [7].

The size MSD can be determined by measuring the largest diameter or an average of three diameters that compares 5-12 weeks of MSD as shown in Fig. 2. Gestational age is equal to 4 weeks plus (sac diameter (mm) × days). It relies on the gestational sac with normal growth of 1 mm per day after the 4th week of pregnancy. For example, a gestational sac size of 11mm would be about 5 weeks and 4 days gestation (4 weeks plus 11 days = 5 weeks and 4 days).

There are several steps to obtain gestational age information processing by a computer. They are shown on Fig. 3, which is an image-processing pipeline that has objective to improve the ultrasound image, to separate fetus object from other objects, and to calculate CRL or MSD based on pixel-length, from head to rump or a longest sac diameter. The pipeline processes could be a bit different between CRL to obtain fetus area and MSD to obtain sac area.

Input images of ultrasound obtained from Internet sources of pregnant mothers. All images have necessary information about the fetus age. Filtering process desires to remove noise on the ultrasound image.

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The used filter operator is Gaussian Blur [8] that make image blur for eliminating image noise. It uses a Gaussian kernel hump-shaped Gaussian bell-shaped, 5×5 kernel, and σ=1.0. These operators do as a pre-processing in order morphology process produces a better result.

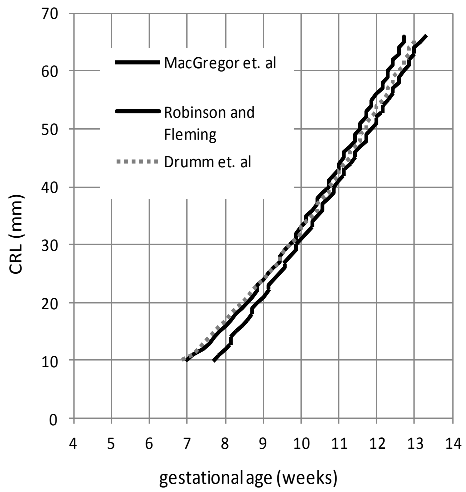

Figure 1. Crown-Rump Length (CRL) chart

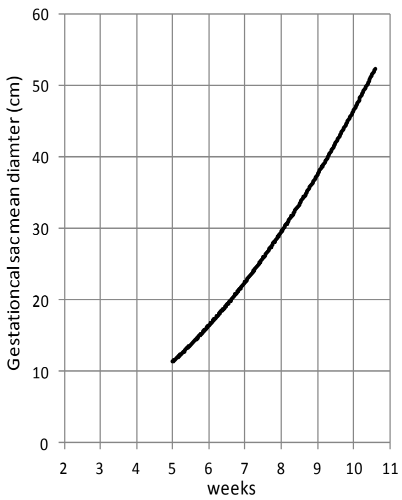

Figure 2. Mean Sac Diameter (MSD) chart

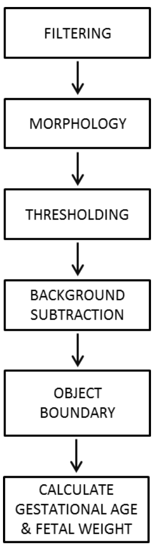

Figure 3. Pipe line for CRL and MSD determination

Thresholding is widely used in image-based applications [9]. It is useful to separate the object of interest with an image area corresponding to the background. Thresholding provides an easy and convenient way to do this segmentation based on different color intensities between foreground and background. Input for thresholding operation is usually grayscale, while the general output is a binary image, black pixel for the background and white pixel for the foreground. Determination of color pixels arranged based on the value of the threshold intensity.

Morphological tools are enhancement stage to process and modify the shape and structure of an object image. Two of the most basic morphology operators, namely the opening and closing are made based on a combination of dilation and erosion operators. The erosion of a set A by a SE (Structure Element) B is defined as:

$$A \ominus B = \{z \mid (B)_z \subseteq A\} \tag{1}$$

The result is the set of all points z such that B translated by z is contained in A. The benefits of the erosion can split apart joined objects and strip away extrusions. In the other word, erosion will lean an object. SE Are small sets or sub-images used to examine the image under study for properties of interest [10].

The dilation of a set A by a SE B is defined as:

$$A \oplus B = \{z \mid [(\hat{B})_z \cap A] \subseteq A\} \tag{2}$$

The result is the set of all points z such that the reflected *B* translated overlap with *A* at least one element. Dilation operator will fatten up the object. The opening of set *A* by structuring element *B* is defined as:

$$A \circ B = (A \ominus B) \oplus B \tag{3}$$

which is an erosion of *A* by *B* followed by a dilation of the result by *B*. The closing of set *A* by structuring element *B* is defined as

$$A \bullet B = (A \oplus B) \ominus B \tag{4}$$

which is an dilation of *A* by *B* followed by an erosion of the result by *B*.

The objective of background subtraction is to separate a fetus object or a sac object from other objects based on their contour. These can be done by select and give a color on the fetus or sac area [11]. The subtraction of the fetal object uses boundary fill algorithm. It fills and gives a specific color in a region that has a closed form of interconnected pixels. It is an easy way to fill boundary area by selecting the shape object and began to flood it with color. It is an easy way to fill color in the graphics. One just takes the shape and starts boundary fill [12]. This algorithm works by giving the color of the pixels within the object boundary as well separating pixels outside of the object boundary.

After an image has been segmented, the detected region needs to be described (description process) in the form more suitable for further processing [13]. The segmented objects have a set of pixels that constituting their region boundaries. They characterize a shape of an object. To determine it is a fetus shape or a sac area by a computer needs extra works. However, when dealing with a region or object, several compact representations are available that can facilitate manipulation of and measurements on the object. In each case we assume that we begin with an image representation of the object.

To obtain gestational age through CRL and MSD requires a parameter length, then the boundary of interested objects, fetal boundary and sac boundary, are required. Contour tracing Operator (Chain code) is used to represent a boundary by a connected sequence of straight-line segments of specified length and direction. This representation is based upon the work of Freeman. It follows the contour in a clockwise direction and keeps track of the directions as it goes from one contour pixel to the next. Typically, chain code is based on the four- or eight-connectivity neighborhood for the standard implementation of an object pixel that has a background (non-object) pixel.

Calculation of gestational age and fetal weight from CRL and MSD calculation is obtained from the longest pixels of fetal boundary and sac boundary in pixel unit. Based on its image resolution, dpi (dot-per-inch), the number of pixel length can be converted into centimeter unit. The gestational age can be estimated by the CRL chart as shown in Fig. 1 and by the MSD chart as shown in Fig. 2.

III. Results

Sample images that used on this experiment are listed on Table I. They have CRL values examine by doctors. This table provide conversion measurement unit, from pixel unit until centimeter unit.

TABLE I. Sample Image of Ultrasound

No.	Length (pixel)	Width (pixel)	dpi	Length (inch)	Width (inch)	Length (cm)	Width (cm)	CRL (cm)	MSD (cm)
1	390	260	96	4.06	2.70	10.31	6.87	5.8	9,3
2	390	260	96	4.06	2.70	10.31	6.87	7.1	11,4
3	390	300	96	4.06	3.12	10.31	7.93	3.8	5,9
4	410	330	96	4.27	3.43	10.84	8.73	4.1	6,6
5	400	231	96	4.17	2.40	10.58	6.11	6.0	11,2
6	640	480	150	4.27	3.20	10.83	8.12	9.0	12,8
7	615	345	96	6.40	3.59	16.27	9.12	5.7	9,1
8	650	448	96	6.77	4.67	17.19	11.85	7.2	11,5
9	349	252	150	2.32	1.68	5.90	4.26	6.3	10,1
10	390	300	96	4.06	3.12	10.31	7.93	5.0	8,0

One cycle process in determining automatic CRL is shown in Fig. 4. Blurring process of original image (a) was implemented on image (b). This process unites small objects that surrounding a large object. Opening process is done by process on erosion (c) and dilation (e) to reduce noise components smaller than SE. The process of median blur is inserted between those processes (d). The aim is the same, combine small objects with a large object around it.

The size of the dark noise elements in the fetus structure increased (inner dark structures). Then reduced the size of inner noise or eliminated the noise. However, the opening between the fetus ridges created new gaps. Closing process reduces the new gaps between the ridges bit it also thickening the ridges. Otsu threshold operator (f) makes the image into a binary that displays information about the fetus as a foreground object and abdomen as background. Fetus object separated from the background through a process of subtraction (g) and generate the object using the boundary segmentation process (h). Drawing line of CRL is done by calculating the maximum distance among points of boundary object (i). Even the process of CRL line takes some time, for this study, it can represent the CRL in automatic manner.

Conversion of length in pixels, dpi unit, centimeter unit, and then gestational age is done according to Fig. 1. In this case of sample 4 shown in Fig. 4, the CRL length according automatic CRL estimation is 8.1cm that is double than doctor examination, which is 4.1cm.

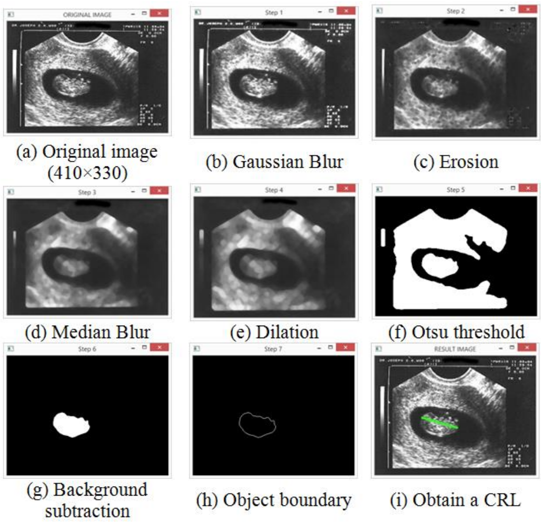

Figure 4. Image processing of CRL estimation

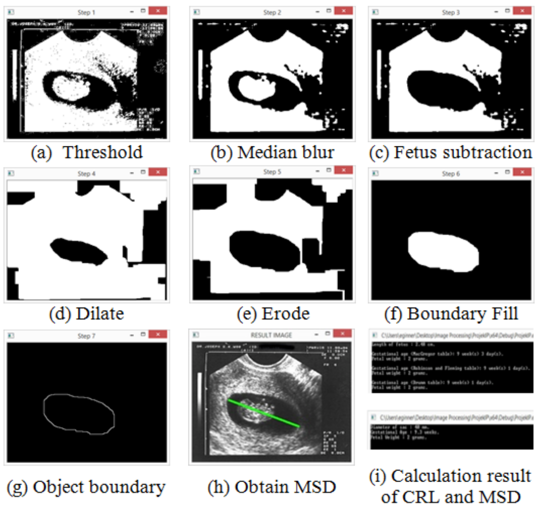

Figure 5. Image processing of automatic MSD estimation

All results of automatic CRL estimation are listed on Table II. The successive of fetus detection using CRL is 60% of 10 samples.

One cycle process in determining automatic MSD is shown in Fig. 5. The process for calculating the MSD is slightly different with the CRL process. Filtering of original image is begun using threshold (a) and Median blur. Fetus subtraction (c) is done using template fetus area from Fig. 4(g) to obtain an image background. Small object then is vanished by closing operator, which are dilate (d) and erode (e). Filling the hole of the closed area of interconnected pixels with a specific color (f). Object boundary of sac area (g) is shown. Calculation of CRL and MSD (h) is presented in Fig. 5(i).

Conversion of length in pixels, dpi unit, centimeter unit, and then gestational age is done according to Fig. 2. The successive of fetus detection using MSD is 70% of 10 samples as listed on Table III.

TABLE II. COMPARISON OF CRL BETWEEN MEDICAL TEST AND AUTOMATIC CRL ESTIMATION

No	Medical test		Fetus detection	Automatic		Different (cm)
	CRL	Age		CRL	Age	
1	5,8	12W	Yes	7,1	12W	1,3
2	7,1	13W	Yes	8,9	14W	1,8
3	3,7	11W	Yes	9,0	14W	5,3
4	4,1	11W	Yes	8,1	13W	4,0
5	7,0	12W	Yes	10,0	15W	3,0
6	8,0	23W	Yes	6,8	12W	1,2
7	5,7	12W	No		-	-
8	7,2	13W	No	-	-	-
9	6,3	12W	No	-	-	-
10	5,0	12W	No	-	-	-

TABLE III. COMPARISON OF MSD BETWEEN MEDICAL TEST AND AUTOMATIC MSD ESTIMATION

No	Medical test		Fetus detection	Automatic		Different (cm)
	MSD	Age		MSD	Age	
1	9,3	12W	Yes	10,7	12W	1,4
2	11,4	13W	Yes	13,4	14W	2,0
3	5,9	11W	Yes	13,5	14W	7,6
4	6,6	11W	Yes	12,2	13W	5,6
5	11,2	12W	Yes	15,0	15W	3,8
6	12,8	23W	Yes	10,2	12W	2,6
7	9,1	12W	Yes	10,8	12W	1,7
8	11,5	13W	No	-	-	-
9	10,1	12W	No	-	-	-
10	8,0	12W	No	-	-	-

IV. SUMMARY

The use of image processing in the research pipeline reporting to separate the object of the fetus and uterine sac of other organs or background is quite satisfactory. This success is 60% for CRL and 70% for MSD, sequentially. Object of the fetus and uterine sac is detected can be separated as a major influence of segmentation stage. Inaccurate calculation of estimated CRL and MSD compared to the doctor can be improved, when using an ultrasound image of the same machine.

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REFERENCES

[1] K. Butt and K. Lim, "Determination of gestational age by ultrasound," *SOGC Clinical Practice Guidelines*, vol. 36, no. 2, pp. 171-183, February 2014.

[2] D. B. Karki, U. K. Sharmqa, and R. K. Rauniyar, "Study of accuracy of commonly used fetal parameters for estimation of gestational age," *JNMA J. Nepal Med. Assoc.*, vol. 45, no. 162, pp. 233-237, June 2006.

[3] U. M. Reddy, R. A. Filly, and J. A. Copel, "Prenatal imaging: Ultrasonography and magnetic resonance imaging," *Obstet. Gynecol.*, vol. 112, no. 1, pp. 145-157, July 2008.

[4] S. MacGregor and R. Sabbagha, "Assessment of gestational age by ultrasound," *Glob. Libr. Women's Med*, 2008.

[5] INTERGROWTH-21st, *International Fetal and Newborn Growth Standards for the 21st Century*, University of Oxford, 2010.

[6] P. Loughna, L. Chitty, T. Evans, and T. Chudleigh, "Fetal size and dating: Charts recommended for clinical obstetric practice," *Ultrasound*, vol. 17, no. 3, pp. 160-166, 2009.

[7] P. C. Jouppila, "Length and depth of the uterus and the diameter of the gestation sac in normal gravidas during early pregnancy," *Acta Obstet. Gynecol. Scand.*, vol. 50, pp. 29, 1971.

[8] G. Dougherty, *Digital Image Processing for Medical Applications*, Cambridge: Cambridge University Press, 2009.

[9] R. C. Gonzales and R. E. Woods, *Digital Image Processing*, 3rd ed., Pearson, 2010.

[10] K. Pulli, A. Baksheev, K. Kornyakov, and V. Eruhimov, *Real-Time Computer Vision with Opencv*, Acmqueue, 2012.

[11] S. Rueda and S. Fathima, "Evaluation and comparison of current fetal ultrasound image segmentation methods for biometric measurements: A grand challenge," *IEEE Transactions on Medical Imaging*, vol. 33, no. 4, pp. 797-813, 2013.

[12] Hermawati and F. Astuti, *Pengolahan Citra Digital Konsep & Teori*, Penerbit Andi dan Universitas 17 Agustus 1945 Surabaya, 2013.

[13] N. M. Zayed and A. M. Badwi, "Wavelet segmentation for fetal ultrasound images," 2009.

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