Ellipse Detection on Embryo Image Using Modification of Arc Particle Swarm Optimization (ArcPSO) Based Arc Segment

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***Abstract*—In Vitro Fertilization (IVF) technology is used to help couple that have problem in their reproduction organs. However, the success rate of IVF is just 30%, so it is a challenging task to increase that success rate. In this paper, we proposed an ellipse detection method on single and multiple embryo image by modifying the ArcPSO method on ellipse fitting process and the process on extract the arc segment for ellipse detection. The experiment results on single embryo data showed that the proposed method has a 24% better on F-Measure, 21% better on precision, and 28% better on recall as compared to the original ArcPSO method. While the experiment results on multi embryo data showed that the proposed method has a 7% better on F-Measure, 11% better on Precision, and 2% better on Recall as compared to the original ArcPSO method.**

***Keywords*—IVF, ellipse detection, ArcPSO, arc segment**

I. Introduction

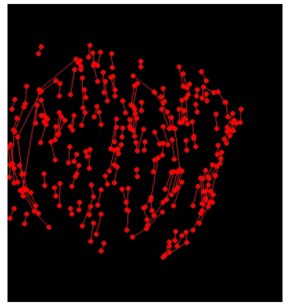
Almost all married couples wants to have children, unfortunately some couples experience infertility caused by various factors, including abnormal sperm production, over exposure to certain chemicals and toxins, ovulation disorders, cancer and its treatment, and certain medications. There are several options for treating infertility, one of them is In-Vitro Fertilization (IVF). IVF is a method of reproduction in which the womans egg is fertilized by the mans sperm outside the body. During the process of IVF, eggs and sperm are placed in a laboratory dish and incubated within a few days. The fertilized egg, called an embryo, will be returned to the woman's uterus through the cervix. Monitoring process using time-lapse imaging was performed to evaluate the embryo. Thousands of pictures will be taken to record the cell division of fertilized egg. This method requires a considerable cost, a long time, and a high degree of accuracy because the doctor is required to observe the entire image, which allows for error evaluation. Therefore, it takes an approach to detect embryos automatically in order to assist doctors in the process of selecting embryos to be inserted into womans uterus.

Based on the literature reviews, there are two main research on embryo detection. F. Moussavi [5] proposed a method to track human embryo in time lapse microscopy using Conditional Random Field (CRF), but this method cannot be used for single embryo image. Another research on embryo detection is done by Cicconet [7] which proposed a method for ellipse finding and fitting of embryo data. However, this method failed to extract the edge on the embryo image, so it impacts on the failure to detect an ellipse. In addition to these two studies, El-Shenawy [8] also proposed an automatic detection of embryos to determine its quality. The study was conducted by comparing several approaches for embryo detection, like Hough Transform and template matching, as well as used sobel edge detection method to get the edge from the embryo image. However, the results contained noises which is extracted as an edge.

Embryo detection can be done by looking at the morphology which has an elliptical shape. Ellipse detection can be performed using statistical methods, evolutionary algorithm, and combination of an existing method. H.D. Cheng [6] has developed a method that aims to detect an ellipse by combining the evolutionary algorithm, Hough Transform, and also used Particle Swarm Optimization (PSO) to speed up the computation process by spreading a swarm on edge pixels and the fitness function in this case is ellipse parameter. Swarm will move to the point or parameters which have the highest fitness function, thus the ellipse can be detected.

In this paper, we have developed a method for ellipse detection on embryo images by modifying ArcPSO method [1]. ArcPSO is an ellipse detection method which utilizes Particle Swarm Optimization (PSO) and combination of arc segment. Modification will be done in 3 step, the first step is to modify the process of arc segment extraction. This step is essential because in some cases, the ArcPSO can not be extracted the arc segment, and it caused the failure to detect an ellipse on embryo image. An example of this case can be seen in Figure 1.

The second modification is done by adding a distance parameter to choose the arc segment candidate. This modification is needed because these methods has a tendency to find the largest ellipse as can be seen in Figure 6. It is caused by the fitness function defined on this method which will find the longest exist arc to form ellipse. The third modification will

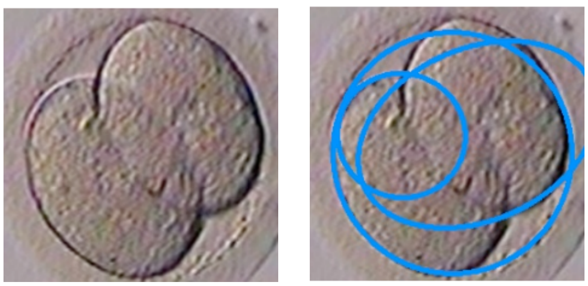




(a) Input Image

(b) Result of Standard Arc Segment Extraction

(c) Result of Modification Arc Segment Extraction

Fig. 1: Examples of cases where arcPSO can not extract the arc segment



(a) Input Image

(b) Ellipse Detection Result using ArcPSO

Fig. 2: Examples of Multiple Ellipse Detection

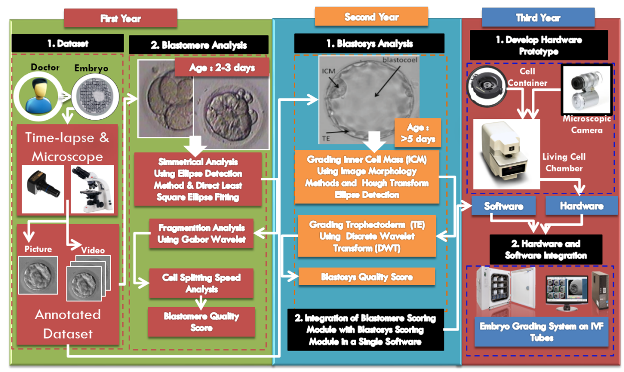


Fig. 3: Research on Embryo Grading System

be done by use all point in the arc segment and used direct least square for ellipse fitting. This method will be tested on 24 - 48 hours embryo development with various image resolution (300 - 600 pixels).

The proposed method in this paper aims to automatically detect embryos, so that the category of the embryo could be known and compared in accordance with the predetermined criteria given by the embryologist. Based on M. Meseguer's research [10], the morphology knowledge of an embryo is important. Afterwards, the time-lapse of an embryo could then be classified. Therefore, the focus of this paper is the detection of embryos in a single image.

The method proposed in this study is a part of a bigger research. The research is to design and implement an embryo grading system. This research is conducted in three stages. The first stage is to gather embryo data using time-lapse method and microscope. The time-lapse gathers embryo images every 5 minutes. The dataset includes blastomeres that are 2-3 days old. The simmetricity of those blastomeres will be analyzed using ellipse detection.

The next stage is to analyze blastosys, which occurs when the embryo's age reaches 5 days. In this stage, we planned to use image morphology technique and hough transform ellipse detection to grade the Inner Cell Mass (ICM) of the embryo. The score will then be combined with the score of the blastomere grading. The last step is to create a prototype of the hardware of this system. The hardware have a microscopic camera built in to the living cell camber. The system could the automatically detect the embryos condition using methods developed previously.

This paper proposes a method that is in the first stage of the research. The embryo detection using ellipse is the focus on this paper as well as this research stage. The details of this research are described in Figure 3.

The remainder of this paper is organized as follows: In Section 2 we described the theory of the ArcPSO method and modification on ArcPSO method. Details of data set, evaluation metrics, experiments result and analysis are described briefly in Section 3. The conclusion about the significance of the results in this work described in Section 4.

II. The Algorithm

This section will describe ArcPSO as the base line algorithm and modification on ArcPSO method.

A. ArcPSO

The ArcPSO is an ellipse detection method proposed by Aprinaldi, et al [1]. The method specifically detects multiple ellipse that forms the outline of several embryos. This method combines Particle Swarm Optimization Algorithm (further abbreviated as PSO algorithm) as a fitness function for detecting the ellipse and Arc Detection method to detect several arcs that forms an ellipse. The process of detecting ellipse using ArcPSO starts by detecting edge segments of the image. The edge detection method will be performed by using EdgeDrawing algorithm, which uses heuristic process to connect several detected anchor points from the image [3] [2]. Afterwards, the detected lines from the EdgeDrawing algorithm will be validated using Helmhotlz Principle. The Helmhotltz principle will basically remove lines that have a lowest possibility of being an edge. The process will completely remove the lines from the image, leaving only the lines that has the highest possibility to be edges.

After the edge detection method have been performed, the next stage is to detect ellipse using PSO algorithm. The method will first detect 5 points that forms an ellipse by using the following equation:

$$x^2 + y^2 - U(x^2 - y^2) - 2Vxy - Rx - Sy - T = 0 \tag{1}$$

Algorithm 1 Standard Arc Grouping

procedure FINDPOTENTIALARCLINES($v1..vn$)
  ▷ v1..vn is list of line segment ▷ MinimumAngle is 2 degrees and MaximumAngle is 170 degress
  $i \leftarrow 1$
  while $i < n$ **do** ▷ Find an initialization line
    for $i \leftarrow 1, n$ **do**
      if $\Theta_i \geq MinimumAngle$ && $\Theta_i \leq MaximumAngle$ **then** break
    for $j \leftarrow i + 1, j < n$ **do**
      if $sign_{j-1}\ ! = sign_{i-1}$ **then**
        break ▷ The different angle
      if $\Theta_j < MinimumAngle \parallel \Theta_j > MaximumAngle$ **then** break
      if $abs(sign_{j-2} - sign_{j-1} > 10)$ **then** ▷ for each x or y coordinates respectively
        break
      if $sign_i.length > 50$ **then**
        break
      if $j - i + 1 \geq 1$ **then**
        $tempArc.initialize$ ▷ Initialize tempArc into a temporary variable
        for $k \leftarrow i, k < j$ **do**
          $LengthOfArc = sign_{k-1}.length$
          if $LengthOfArc > 1$ **then**
            $tempArc.length = LengthOfArc$
      $SortArc$ ▷ Sort the beginning and end of the Arcs

Afterwards, the method will use those detected sample points as the fitness value of the PSO particles. The PSO particle uses Hough Transform Voting. The PSO algorithm particles are represented as the ellipse equations (semiminor axis, semimajor axis, middle points, and incline of the ellipse). The algorithm will search the particle with the highest fitness function to be considered an ellipse. The fitness function is evaluated by considering the total arc length of the ellipse particle.

Algorithm 2 Modification of Arc Grouping

procedure FINDPOTENTIALARCLINESMODIF($v1..vn$)
  ▷ v1..vn is list of line segment ▷ MinimumAngle is 6 degrees and MaximumAngle is 60 degress
  for $x \leftarrow 0, x < n$ **do**
    while $y < n$ **do**
      if $statusLoop3 == false$ **then**
        if $linesegmentdistance < distancethreshold$ **then**
          if $\theta_i \geq MinimumAngle$ && $\theta_i \leq MaximumAngle$ **then**
            $statusLoop3 \leftarrow true$
            $addLineSegment$
              ▷ and give a flag to the line that has been processed
            break
      if $statusLoop3 == true$ **then**
        for $zz \leftarrow y + 1, zz < n$ **do**
          if $linesegmentdistance < distancethreshold$ **then**
          if $sign_y == sign_z z$ **then** ▷ different angle
          if $\theta_j < MinimumAngle$ && $\theta_j > MaximumAngle$ **then**
            $rmse \leftarrow FitCircle(vi..vnow)$
            if $rmse < 1.5$ **then**
              $addLineSegment$ ▷ and give a flag to the line that has been processed
              $statusIncrementLoop2 \leftarrow false$
              break
      if $statusIncrementLoop2 == true$ **then**
        $yy+ = 1$
      else if $statusIncrementLoop2 == false$ **then**
        $statusIncrementLoop2 \leftarrow true$
  if $LineSegment \geq 2$ **then**
    $addLineSegmentToListArc$ ▷ and remove the line that has been processed
    ▷ Looking for arc segment again
  $statusLoop3 \leftarrow false$
  $yy \leftarrow 0$

B. Modified ArcPSO

In this paper we make two modification on a standard ArcPSO, there are modification of arc segment extraction and modification of PSO for ellipse detection. The fundamental modifications performed on the arc segment algorithm by changing the process to extract the arc segment, adding distance parameter, and changing the process of ellipse fitting. The detail of the modification will be describe in this section.

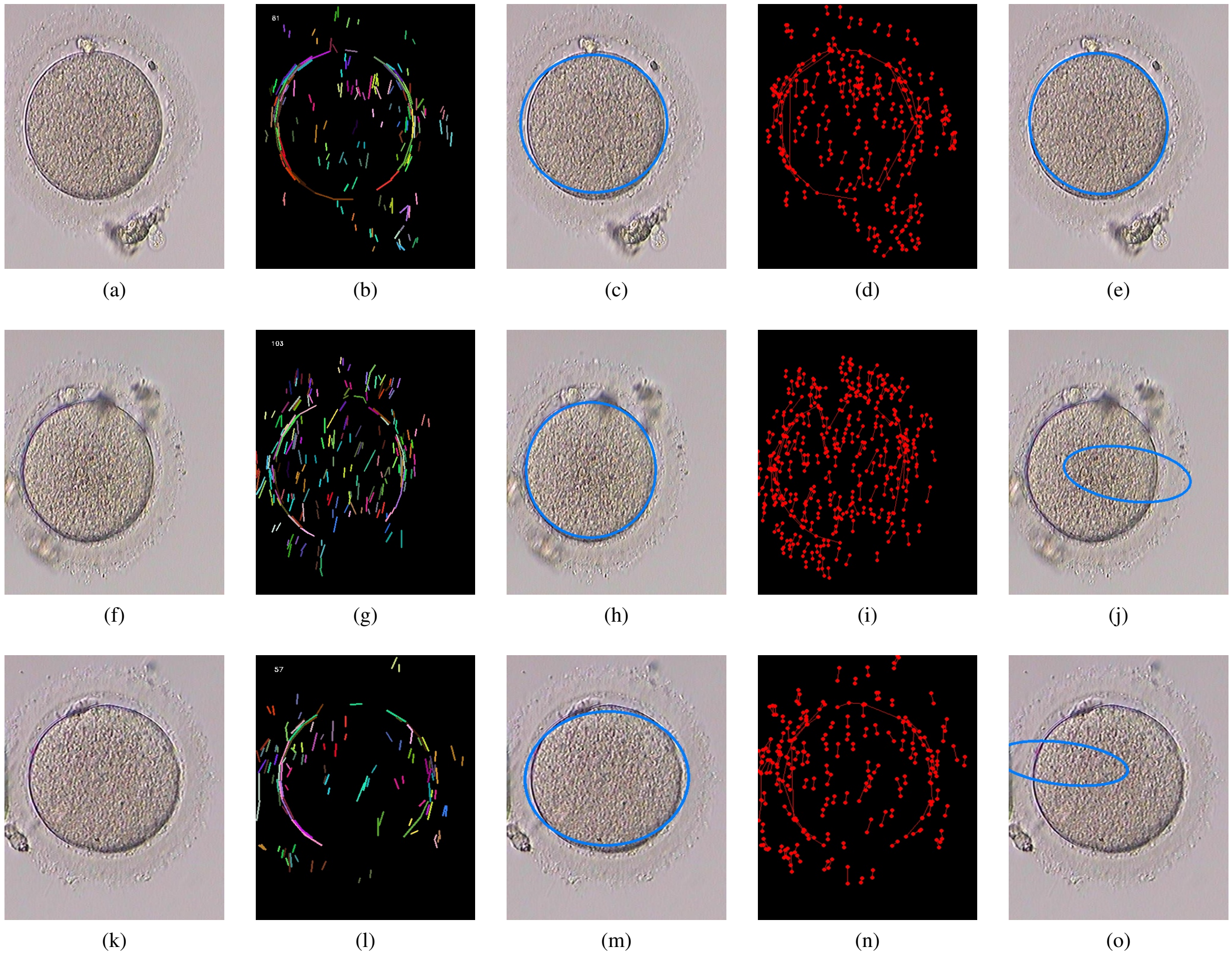


Fig. 4: Experiment Result of Ellipse Detection On Single Embryo Image. [4a, 4f, 4k] Example of input image, [4b, 4g, 4l] Modification of Arc Segment, [4c, 4h, 4m] Detection result using the proposed method, [4d, 4i, 4n] Standard Arc Segment, [4e, 4j, 4o] Detection result using standard ArcPSO.

1) Modification of Arc Segment Extraction: There are two modification of arc segment extraction : The first modification has done on the process of arc segment extraction, it can be seen on algorithm 2. The standard algorithm 1 was modified because this algorithm is not good enough to extract the arc segment on multiple ellipse dataset. This is due to the possibility of combining the arc segment with a large distance. Furthermore, original ArcPSO did not check the mean square error of circle fit to maintain the curve of arc segment when merging line segment to arc segment. Otherwise, modification of ArcPSO will check the errors in the merging process of arc segment, if the mean square error of the merging process between line segment and arc segment have a value less than 1.5 pixels, the arc segment will be combined and vice versa. Comparison results of the arc segment extraction between the original ArcPSO and modified ArcPSO shown in Figure 6, it can be seen that the modification of ArcPSO algorithm can produce better arc segment than the original ArcPSO because the shape of ellipse is more compact, making it easier for the next ellipse detection process. The differences color on Figure 6 represented different arc segment.

The second modification of arc segment extraction has done by adding distance parameter. The reason for adding edge distance parameter is due to the characteristics of the blastomere ellipse whose position is close to each other. The distance parameter is used when extracting the arc segment whose value according to the threshold, in this paper we use 12 pixels for the threshold value, where it is determined based on the results of experiments that have been done.

2) Modification of Ellipse Fitting Process: The modification on ellipse fitting process has done because the parameter of original ArcPSO just used 5 representative point of arc segment to fit the ellipse fitting, whereas the arc segment has many point so it cause the ellipse fitting result did not smooth and also lead to the false of ellipse fitting. Therefore, this modification algorithm use all of the point in arc segment and also use direct least squares for ellipse fitting [4].

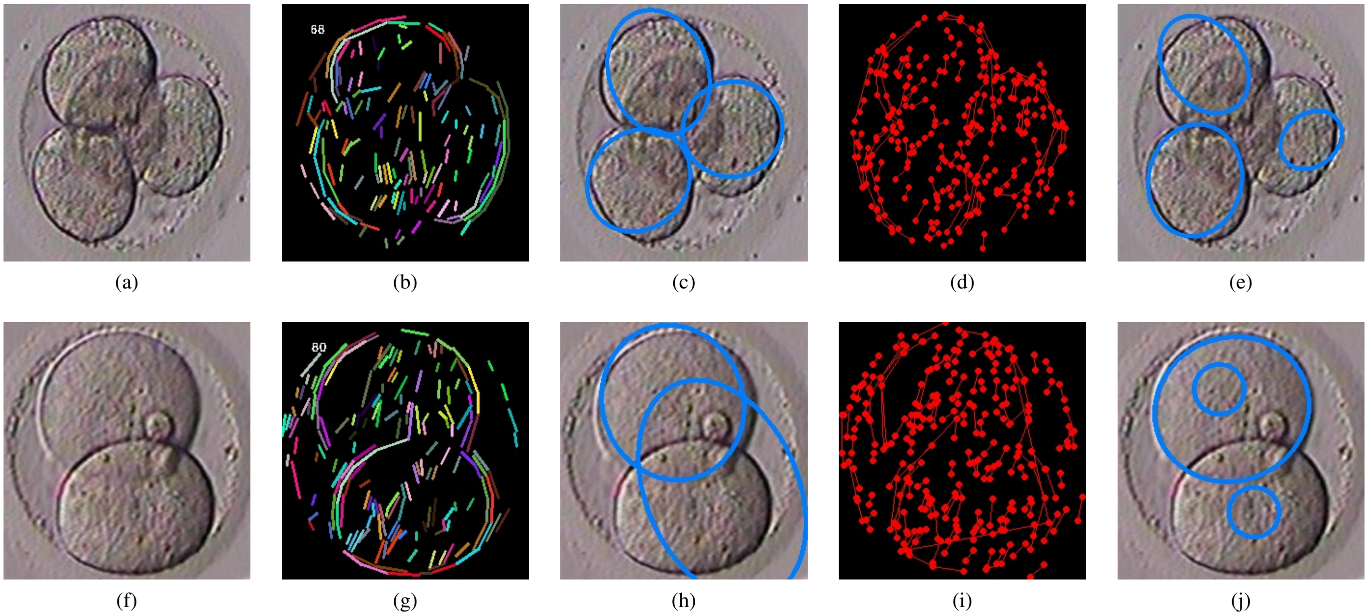
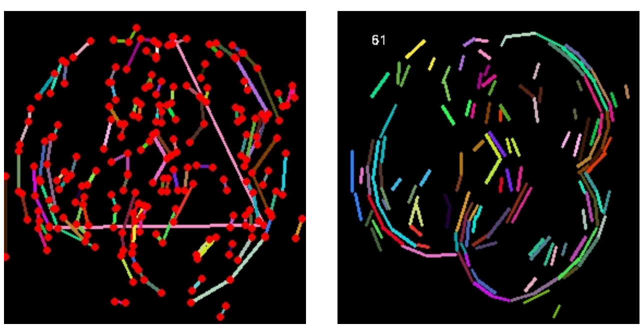


Fig. 5: Experiment Result of Ellipse Detection On Multiple Embryo Image. [5a, 5f] Example of input image; [5b, 5g] Example of Modification Extraction Arc Segment Process; [5c, 5h] Detection result using the proposed method; [5d, 5i] Example of Standard Extraction Arc Segment Process; [5e, 5j] Detection result using ArcPSO.



(a) Original ArcPSO (b) Modification ArcPSO

Fig. 6: Result of arc segment extraction

III. Experiments and Evaluations

Experiment on several scenarios were conducted to evaluate the performance of the proposed method and compare it with the previous method. The dataset that used in this paper is an embryo digital image on the process of In Vitro Fertilization (IVF) in the first and second day after fertilization which is performed in Yasmin IVF Clinic, Dr. Cipto Mangunkusumo General Hospital - Jakarta, Indonesia. The dataset consists of 88 embryos where 20 images contains more than one blastomeres. The dimension of embryo images is ranges from 300 to 600 pixels for single embryo image and 200 to 400 pixels for multi embryo image. The proposed method is implemented in C++ using Microsoft Visual Studio Professional 2010 IDE and OpenCV 2.4.8 library for image processing.

A. Evaluation Metrics

We evaluate the performance of the algorithm by measuring the accuracy, recall, F-measure with the following formulas [9]:

$$precision = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Positive\ (FP)} \tag{2}$$

$$recall = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Negative\ (FN)} \tag{3}$$

$$F - measure = \frac{2 * precision * recall}{precision + recall} \tag{4}$$

True Positive (TP) represents the condition when the algorithm can detect an existing blastomere correctly. False Positive (FP) represents the condition when the algorithm detects a blastomere that does not exist or detect the same blastomere more than once. False Negative (FN) represents the condition when the algorithm failed to detect an existing blastomere. High precision value shows that the method gives relevant results (correctly detected) more than irrelevant result (incorrectly detected), and high recall value shows that the detection method gives results which are mostly relevant. While the F-measure is calculated to measure the overall performance of detection methods. The highest value of the F-measure is 1 while the lowest value is 0.

B. Experiment Result

The experiment results of our experiment can be seen on Table I for single embryo data and Table II for multi embryo data. It can be seen that our proposed method have a better precision value with the difference of 21%, recall value with the difference of 28%, and F-Measure value which represent the overall performance with the difference of 24% as compared to the original ArcPSO method in a single ellipse detection. While for multiple ellipse detection, our proposed method also have a better result with 11% better on precision, 2% better on recall, and 7% on F-Measure as compared to the original ArcPSO method. This better result is due to the proposed method can extract better arc segments than the original ArcPSO, so it is improve the detection of ellipse in embryo image. With the addition of distance parameter to choose the arc segment and the use of all point in the arc segment for ellipse fitting make our algorithm has a better performance to extract the arc segment.

The arc segment from both of the methods could be seen on Figure 4 and Figure 5.

TABLE I: Ellipse Detection on Single Embryo

Method	Precision	Recall	F-measure
ArcPSO	0,59	0,68	0,63
Modification of ArcPSO	0,80	0,96	0.87

TABLE II: Ellipse Detection on Multi Embryo

Method	Precision	Recall	F-measure
ArcPSO	0,31	0,28	0,29
Modification of ArcPSO	0,42	0,30	0.36

IV. Conclusion

The modification of ArcPSO, by changing the process to extract arc segment, adding distance parameter, and changing the process of ellipse fitting, is to improve ArcPSO in detect ellipse on an embryo image. ArcPSO is used as a baseline method because ArcPSO can extract the edges from input image, especially embryo images that can not be done by standard edge detection like canny edge detection. Based on the experiment result, it can be concluded that the proposed method improve the performance of ArcPSO for ellipse detection on embryo image because it has better mechanism to extract the arc segment and the process of ellipse fitting. The proposed method gave the difference F-Measure value 24% to detect single embryo image and 7% to detect multiple ellipse.

Acknowledgment

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