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Automatic Human Sperm Concentration in Microscopic Videos

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Abstract

Background: The process of counting human sperm cell studies are of noteworthy interest to biologists researching sperm function and to medical practitioners in charge of mitigating male infertility. Currently, this assessment is performed manually by observing the sperm samples through a phase-contrast microscope using expert knowledge to do a subjective quality judgment.

Aims: To eliminate the subjective and error-prone influences of the manual semen exploration and to evade inter and intra-laboratory discrepancies in semen analysis test results

Methods: This paper, introduces a Computer-Assisted Sperm Analysis (CASA) to infer the concentration of human sperm in three steps: (i) the human sperm pretreatment to be investigated by videos acquired using a microscopic, which consists of a conversion the RGB into the YCbCr color space, the Gaussian filter along with the Discrete Wavelet Filtering (DWF); (ii) segmenting the image in two fold classes: spermatozoa and the background, followed by the Sobel edge detection detector to produce these outcomes; and (iii) distinguishing true sperm from false ones with a classification technique consisting of decision trees and relying on invariant features: the dimensions of the spermatozoid head bounding ellipse as well as its surface.

Results: To test the robustness of the recommended system, the outcomes from automatic and manual tests have been compared. The manual tests have been done by three andrologists. There has been real improvement of precision as well as treatment time, which make this framework useful for groups who intend to design new CASA systems.

Conclusion: In this study, a simple system for automatic concentration assessment of spermatozoa founded on image processing techniques is proposed and implemented.

Keywords: Decision Trees, Discrete Wavelet Transform, Sobel Filter, Human Sperm, Computer-Assisted Sperm Analysis (CASA), Sperm Classification.

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1. INTRODUCTION

Infertility cases have shown an increasing boost in recent years (1). It can impact unfavorably the quality of a couple's life and causes social, as well as emotional problems (2) as stress, depression and sexual apathy (3). Male infertility results most commonly from deficiencies in the semen and the conservative criteria for semen quality. Semen analysis test is required as an initial and most vital stage for male factor infertility appraisal besides treatment therapy determination. This test included a physical examination, hormonal evaluation, sperm parameter determination and genetic analysis (1).The conventional appraisal of sperm parameters at fertility clinics in addition to research laboratories is strenuous and subjective (4) with substantial intra- and inter-laboratory changeability. Typically, the technicians use microscopes to count sperm cells manually. To replace these subjective assessment methods, Computer-Assisted Sperm Analysis (CASA) frameworks are from the 1980s. They are usually thought to deliver objective with repeatable results for semen analysis (5). However the methods used behind these systems are not openly accessed and the results of some CASA were not encouraging enough for some samples. Thereafter, many studies and researches have improved it. An important standard sperm parameter is the sperm concentration or semen density. It is the oldest reported to be investigated during a semen analysis (6). It is reported in sperm/milliliter (mL). According to the WHO (7), the concentration in a normal simple is 15×106 mL and a low concentration is defined as Oligozoospermia.

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2. MATERIALS AND METHODS

2.1- Materials:

The experiment dataset is composed of microscopic video sequence representing sperm motility. To evaluate the proposed CASA system, some sequences have been picked from the dataset used from (8) that contains video recordings corresponding to sperm samples of 30 patients accomplished employing a phase-contrast microscope with an enlargement of ×120 at the Isfahan Fertility and Infertility Center. These video sequences have resolution as well as frame rate of 240 × 320 pixels and 25 fps, correspondingly.

2.2- Methods:

The non-uniform illumination, low contrast, small size of the microscopic images, a high number of sperms and human visual problem, an automated method for sperm concentration is required. As a contribution in the fertility area, the proposed CASA system aims to automate the procedure for measuring the sperm concentration by probing and analyzing a microscopic video sequence of a sperm sample taken according to WHO guidelines and standards (7). As shown in Figure 71, the designed CASA process operates in three steps:

1. The first module performs the pre-treatment of raw microscopic videos, the color space conversion, the contrast enhancement, and the noise reduction phase;
2. The second module separates the spermatozoa from other impurities (debris, seminal fluid, electronic noise) by applying the Sobel boundary detector that leads to a binary image containing white blobs of different sizes. An output image containing the spermatozoa is isolated by means of a thresholding operation on the blobs.
3. The third module receives the output result from the second module, the segmented objects are not all spermatozoa. A classification phase of these objects is necessary. Knowing that the head of spermatozoid has an elliptical shape and almost identical size, two features have been chosen as discriminatory and used in the two-class classification process. The result obtained at this module output is the total number of spermatozoa which means the concentration.

2.2.1 Noise reduction:

Like any artificial vision system, the pre-processing of raw images is a very important step because the whole system has it precision based on it. The poor quality of microscopic images of sperm led us to proceed in several steps. We have been partially inspired by the work in (9,10).

1) Conversion from RGB color space to YCbCr

We have as input a microscopic video recorded 240 × 320 pixels with a frequency of 25 fps. First, an RGB-to-YCbCr color space conversion for each frame of video is required (9). Because of the similarity between the Luminance (Y) component and the original grayscale imageries, this component is used for the subsequent system stage. The expression for performing this conversion is given below (9):

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 65.4821 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -39.786 & -18.214 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

2) Smoothing with a 2D Gaussian Filter

In order to blur the image and reduce details and noise caused by random electrical disturbance in video imaging system, a Gaussian filter was applied on the resulting image. The Gaussian probability distribution function (pdf) for a 1D random variable with mean μ and standard deviation σ is given by

$$f(x,\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}. \qquad (1)$$

For a mean vector $\boldsymbol{\mu}$ and a covariance matrix $\boldsymbol{\Sigma}$, the pdf for a multivariate normal is

$$f(\mathbf{x}) = \frac{1}{\sqrt{(2\pi)^k |\boldsymbol{\Sigma}|}} \exp\left(-\frac{1}{2}(\mathbf{x}-\boldsymbol{\mu})^{\mathrm{T}} \boldsymbol{\Sigma}^{-1} (\mathbf{x}-\boldsymbol{\mu})\right). \qquad (2)$$

3)Filtering with the Discrete Wavelet Transform

Finally, the de-noising is performed using the two-dimensional wavelet transformation. The speed of calculation, even for relatively high decomposition orders, and the good discernibility of the structures turns the framework very effective and widely tool used for reducing digital image noise. This transformation favors a local and non-global study of the image: decomposition is not done in the periodic functions' space but with another class of functions such as Daubechies, Haar, Coiflets, Symmlets .

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After the application of the aforementioned wavelet transform, the Coiflet 2 can be used and this decomposition occurs at level 4 because the noise signals affecting the input images can be extracted at a satisfactory rate while handling appropriate images for supplementary analysis.

2.2.2. ***Sperm edge detection****:*

The process continued with edge detection step. The image at the entrance of this module will therefore go through two competing treatments as follows:

- Median filtering (3 x 3) to suppress impulse noises.
- Sobel edge detector (3 x 3), which performs a 2-D spatial gradient measurement on an image and emphasizes regions of high spatial frequency that correspond to edges (9). So as a result, we get a contours image.

2.2.3. Features extraction

The third module output image is binary and includes blobs having similar sizes to spermatozoa's but with various shapes. To leave only real spermatozoa, this module has for role to identify them and erase the other objects. The adopted solution lies in the exploitation of the elliptical form of the spermatozoid‘s head as well as its surface. To do this, for each blob, the bounding ellipse features and its surface are computed (see Figure 1). Bounding ellipses can be found with the help of the Hough Transform (HT) or investigating the image visually. The handpicked feature vector is v =[a, b, S] T where, for a given ellipse i, the discriminating features are the major axis a $\in$ [4.20, 16.90], the minor axis b< 7.74 , and S$\in$ [55, 200] is the blob area, all measured in pixels.

After that, this feature vector undergoes a basic classification of the type "decision trees" from Figure 2. At this module completion, the output image undergoes labeling and counting processes to get the concentration value.

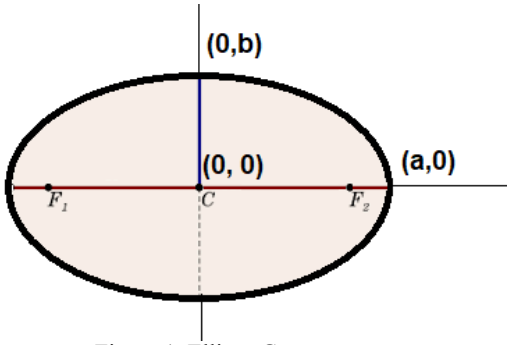

Figure 1. Ellipse Geometry.

As preliminary work of the classification step, we manually analyzed, with the support of andrology technicians, several video sequences of our database and manually measured the limits of the 3 characteristics for spermatozoa. The experimental values found are:

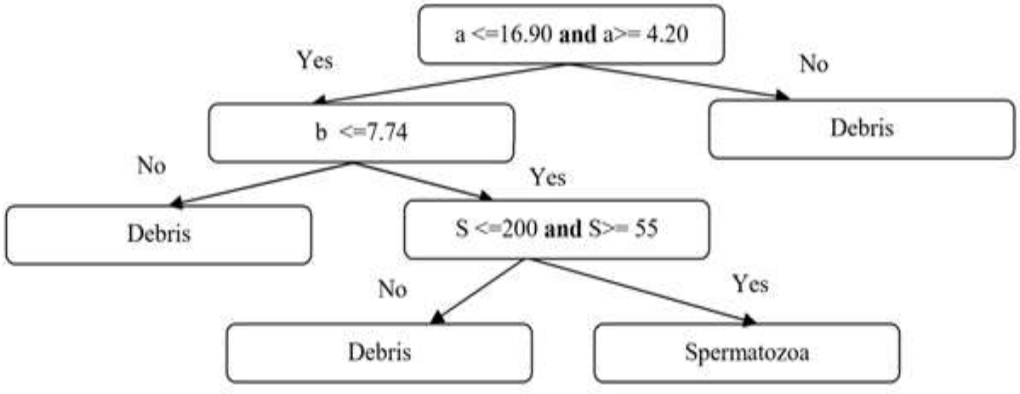

Figure 2. Decision tree organization

3. RESULTS:

The recommended classification scheme works with microscopic video, which gives a satisfactory rate of results in spite of the low quality images (low contrast and small size) of the microscopic. The systems fragmented the videos into frames, each frame is processed by our algorithm.

The steps for the noise reduction stage are exhibited in Figure 3 where Figure 3a has a sperm input image. After mapping these RGB images into the YCbCr color space, their Y components become visible as in Figure 3b where noise is explicitly visible. However, this noise can be alleviated by the

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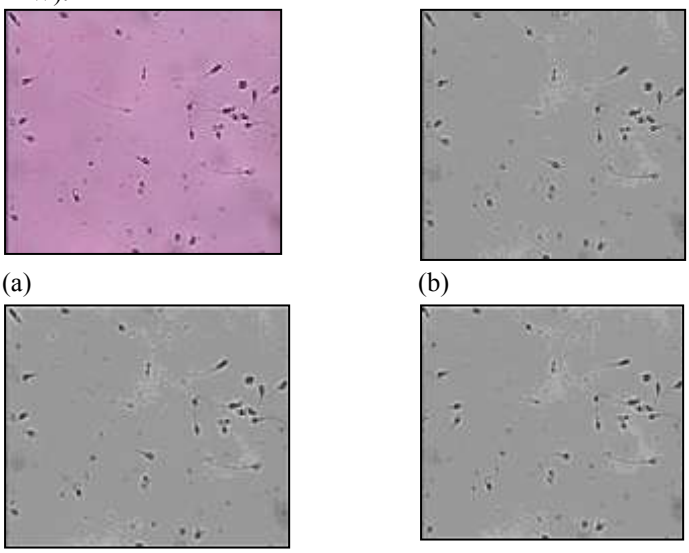
Gaussian filter (i.e., reduce the noise) whose output is in Figure 3c. In this image, the noise is decreased. Still, this amount of signal contamination is not adequate for further processing. So applying discrete wavelet transform is required. Figure 3d represent the output of discrete wavelet transform (DTW).

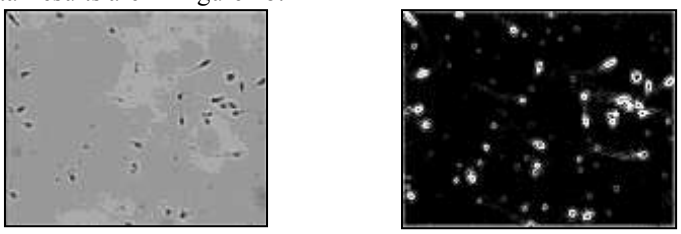


(a) (b)

(c) (d)

Figure 3. Noise reduction steps: (a) RGB input image, (b) Image of the Y component (YCbCr space), (c) Gaussian filtered output, and (d) DWT results.

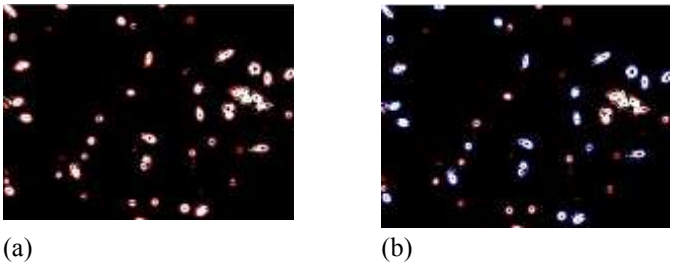
Figure 4 depicts the edge detection stage results that come after eradicating the image noise, as in Figure 4a that contains the output of median filter. The Sobel detector performs edge detection and its experimental results are in Figure 4b.



(a) (b)

Figure 4. Edge detection step: (a) 3×3 median filtered image, and (b) Sobel algorithm output.

Figure 5 indicates the elliptical annotation step for the features extraction. Figure 5a has a complete video frame encompassing a variety of cells and spermatozoids, so that it characterizes a sample for algorithm evaluation. In Figure 5b each elliptic shape corresponds to a detected sperm head.



(a) (b)

Figure 5. Elliptical annotation and feature extractions step. (a) The original image. (b) Detected sperm head with blue color and debris in red color.

After demonstrating the viability of the recommended framework, the focus shift to a comparative study with a statistical system evaluation. The true concentration values are unknown for all videos in the used database. Moreover, even if a commercial CASA system was available, its results would also have demanded three experienced andrology experts to measure manually the values of sperm concentration per video for each one of the 8 video sequences individually for the available database. The attained results for the manual analysis by the three experts and those of our system are in Table 1 in addition to Figure 6.

Table1. Obtained values of concentration by the 3 experts (manual method) and the proposed system (automatic method)

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Videos	Concentration - Manual method					Concentration Automatic method (proposed system)
	Operator 1	Operator 2	Operator 3	Mean Value μ_c	Standard Deviation σ_c	
Video # 1	02	03	03	3	1	02
Video # 2	18	17	16	17	1	17
Video # 3	04	05	06	5	1	05
Video # 4	04	04	03	4	1	03
Video # 5	05	04	04	4	1	03
Video # 6	13	17	15	15	2	15
Video # 7	13	15	16	15	2	16
Video # 8	01	02	02	2	1	03

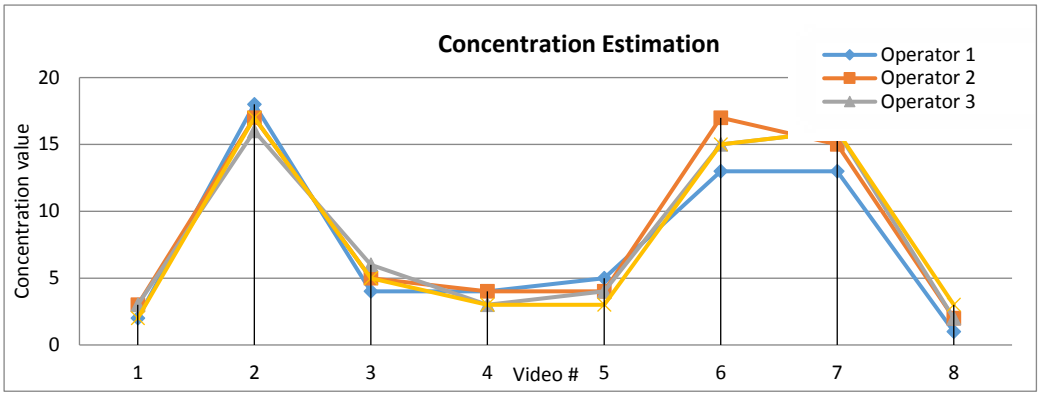

Figure 6. Graphical representation of the obtained values of concentration by the 3 experts (manual method) and the proposed system (automatic method).

4. DISCUSSION

In Table 1, we received two extra columns concerning the manual analysis results of the 3 operators to define the statistical values of μ and σ. We have rounded them because they represent spermatozoids (whole numbers). After examining Table 1 and Figure 6, the concentration values obtained with the proposed CASA system (automatic method) for the 8 video sequences are very precise and close to those obtained manually and are all in the interval: μc ± σc of the manually measured value. This statement can be confirmed graphically by looking at the curve representing the automatic concentration measurements is enveloped by the 3 manual measurements curves to ± σc that appears in Figure 6.

Concluding, the suggested system gives very good results compared to those obtained manually with very good algorithm execution time (nearly 4 times inferior to the time to get a manual analysis by a human expert) as follows:

- The execution time of our algorithm = 80 seconds; and
- The average time of manipulation analysis by a human expert = 300 seconds.

5. CONCLUSION

A semen analysis is a vital examination for spotting male infertility. It measures the concentration, morphology and motility of sperms under the microscope. While using the manual tests is a laborious and subjective task, several other works obtained and treated sperm images to obtain results more objectively. This examination was initially concerned with the automatic detection of the spermatozoids and the associated counting by implementing a CASA system relying on microscopic videos of human semen. It makes evident that the image processing methods, using a decision tree algorithm give a decent classification, and the accomplished outcomes are clearer, more transparent besides easier to comprehend with regard to the manual methods. This designed framework is a substantial achievement towards more sophisticated CASA systems.

Soft computing can be used to reduce problems and augment the number of CASA functionalities as it is done with other computer-assisted medical diagnosis (11, 12, 13, 14, 15, 16, 17, 18, 19). Debris and other fine detail can be investigated with the help of Super-Resolution (15. 19).

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7. Conflict of interest statement

Authors declare no conflicts of interest.

8. Authors biography

No biography

9. REFERENCES

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