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Image Asymmetry Measurement for the Study of Endangered Pygmy Bluetongue Lizard

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***Abstract*—There are applications for the measurement of body asymmetry as some studies have shown a correlation between asymmetry and fitness for some species. In our study of the endangered Pygmy Bluetongue Lizard, the asymmetry of its head is being investigated to see whether this has a correlation with its health and chance of survival in the wild. As there are restrictions on handling the endangered lizards, their digital photos must be taken in the field and therefore it is difficult to impose restrictions on the conditions under which the digital images are acquired. In this paper, we propose a novel automatic technique that is invariant to rotation, size, illumination and tilt, for the measurement of lizard symmetry based on its digital imagery and the resulting symmetry index is used to infer the lizard's asymmetry. The conventional manual methods being used by biologists for fluctuating asymmetry measurement have a number of disadvantages including human errors, and their methods of measurement are based on counting the number of scales and length measurement that do not often agree well with visual assessment. Our proposed image processing technique is non-invasive, robust in a way that will give a similar symmetric index for different images of the same lizard, and more importantly based on the actual image scale pattern of the lizards. Hence our proposed method will also give a better agreement with visual assessment.**

Keywords*— *Fluctuating Asymmetry, image asymmetry measurement, correlation, mathematical morphology.

I. INTRODUCTION

The Pygmy Bluetongue Lizard is an endangered species which was thought to be extinct for thirty years. They are found exclusively in remnant fragments of native grassland in South Australia's mid-north [1], [18], [19]. Fluctuating asymmetry is believed to be a valuable indicator of environmental stress on wild populations. It has widely been used as a phenotypic marker of developmental stability; an ability of individuals to undergo identical development on both sides of bilaterally symmetric metrical traits [2]. Asymmetry may be used for monitoring genetic and environmental stress suffered by natural populations [3], [4]. It has been linked to sexual selection and fitness in some taxa [5]. Many studies have shown a correlation between fitness and asymmetry [3], [6], and this correlation has also been shown to be useful in assessing the status of endangered species [7]. As the Pygmy Bluetongue Lizards endangered status, a non-invasive method, such as image symmetry measurement, would be preferred.

The current methods for measuring fluctuating asymmetry by biologists involve the measurement of linear lengths of bilateral characters, such as leg length, or more novel characters such as the count of head scales [8], [9], [10], [11]. Both methods have a degree of human error as they require the measurements to be taken manually. They are also invasive as they require a large amount of handling of the lizards, or for the animal to be deceased. Furthermore, measurements such as scale numbers do not always agree with visual perception of asymmetry because the shapes of the scales are not taken into consideration. Our proposed technique is based on the scale pattern of the head, the measurement of which gives a result that better agrees with visual assessment. It is also non-invasive as it is based on the digital images of the lizards and it is an automatic process which eliminates human error.

The lizard, refer to Fig. 1 (a), has a unique scale pattern on the head that displays bilateral symmetry which can be used to give a symmetry measurement which will be used to infer its asymmetry. This is done by finding the line of symmetry in the head of the lizard and comparing the scale pattern on each side of the line of symmetry to obtain a measurement of symmetry. Due to the restrictions on handling the Pygmy Bluetongue Lizard, which is an endangered species, the photos need to be taken in the field and hence it is difficult to impose strict criteria on the method by which the photos are taken. It is therefore necessary that the method proposed is robust and invariant to changes in rotation, size, tilt, and luminance. By automatically detecting the line of symmetry, the method is kept invariant from changes in rotation and scale. As the lizards are alive and their posture cannot be easily manipulated, tilt correction is therefore also required. Edge detection together morphological filtering is then used to obtain the scale pattern of each lizard while keeping the method invariant to luminance.

The measure for symmetry is obtained using correlation based on the extracted scale pattern of the left and right half of the lizards head. Higher asymmetry will give a lower correlation result. The two halves are then separated based on the line of symmetry and the correlation is normalized resulting in a value between zero and one. A value closer to one corresponds to a lizard displaying strong symmetry, and closer to zero corresponds to stronger asymmetry.

The organization of this paper is as follows. Section I gives the introduction. In Section II, the image asymmetry measurement method is described, including how the invariance from rotation, scale, tilt and luminance is achieved through the detection of the line of symmetry and the extraction of the scale pattern through morphological filtering and edge detection. Experimental results are given in Section III, and Section IV gives the conclusion.

II. METHOD

The input is a digital image of the lizard's head in which the head has been manually segmented from the background. The colour photos of lizards are then converted to greyscale so that the changes in colour of the lizard at different times of the year will not affect the results. The image symmetry measurement has six stages; first an input image is filtered to remove noise because noise will cause variation in the measurement. A pattern enhancement process is then applied to smooth the image whilst enhancing the scale pattern, which contains the major features for the determination of the symmetry measurement. Edge detection is not applied at this stage because no edge detection algorithm is perfect and any missing edges in the scale pattern in edge detection will cause errors in the measurement. In the third stage, the line of symmetry is found in the lizard using cross-correlation between the image and its mirror image and the image is adjusted so the line of symmetry is vertical and centered. This provides invariance to shift, scale and rotation. The tilt of the lizards head is corrected in the fourth stage, again using cross-correlation, but between the left and right halves of the lizard's head instead. Correcting the tilt provides invariance to the natural posture of the lizard whilst it is being photographed. In the fifth stage, edge detection along with a combination of morphological operations is performed on the image so that the unique scale pattern edges of the lizard are extracted as a binary image. This is done as the final step before the evaluation of symmetry because an intensity image which contains information other than only edges will give more accurate results for finding both the line of symmetry and tilt correction. As a result, the process is invariant to variation in luminance in the open field. The edge detection process also removes unwanted features in between the scale pattern that will have an adverse impact on symmetry measurement. The final stage is the evaluation of symmetry using cross-correlation. A block diagram of the method to produce a measurement of symmetry for each lizard is shown in Fig. 2.

A. Noise Removal

Noise is present and different in every image which will affect the accuracy of the symmetry measurement. A multi-shell median filter, which is a detail preserving filter, is used to remove noise whilst preserving details in different orientations [12], [13]. This preserves the scale pattern of the lizard and improves the robustness of the measurement to different images of the same lizard.

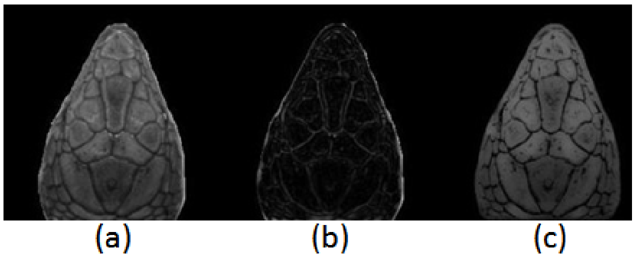

Figure 1. (a) The dorsal surface of the head of the Pygmy Bluetongue Lizard, M_i, (b) The image details, Y, (c) Pattern Enhanced, S_e.

B. Pattern Enhancement

In order to extract as much information as possible from the scale pattern of the lizard, edge enhancement is applied to the image. Edge enhancement serves as a pre-processing step for the line of symmetry and tilt correction steps that follow. Edge detection is not used at this stage as any errors in the resulting edge image, such as missing edges, will have an adverse impact to the accuracy in the steps that follow. The method applied enhances the scale edges which are main features for symmetry measurement, whilst removing unwanted details from the rest of the image. There are two steps to our proposed edge enhancement method; the first is given by (1) whereby the detail of the image, Y, is extracted by taking the difference between a median filter output, P which is an estimation of the background, from the original image, M_i.

$$Y = |M_i - P| \tag{1}$$

The median filter will remove details from the image and hence when its output is subtracted from the original image, M_i, results in the output, Y, shown in Fig. 1 (b), which contains the details of the image. In the second step of the enhancement method, given by (2), Y is subtracted from the original image, M_i, to produce the pattern enhanced image, M_e, as shown in Fig. 1 (c).

$$M_e = |M_i - Y| \tag{2}$$

The output, M_e, is equal to the median filter output, P, except at pixel values where $M_i < P$, i.e. at pixels where the dark edges are. It is because dark edges will be removed by the median filter and be replaced by the brighter background values. Hence, the intensity will be further reduced to produce darker edges in the output, M_e. This is beneficial as the scale pattern is comprised of low intensity values and applying this method effect of enhancing the scale pattern by improving contrast between the scale pattern and the rest of the image as shown in Fig. 1 (c).

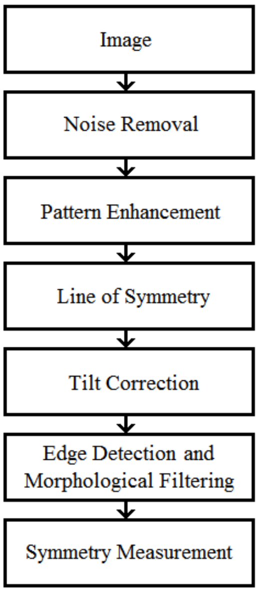

Figure 2. A Flow chart of the algorithm to produce an image symmetry measurement.

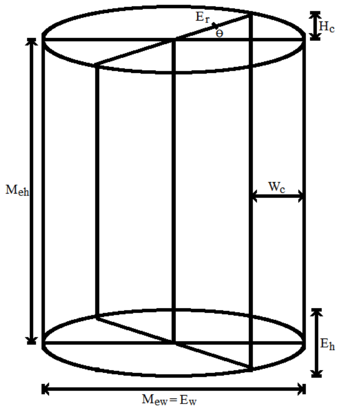

Figure 3. An ellipse used to simulate tilt.

C. Determining The Line Of Symmetry

The definition of bilateral symmetry states that the mirror image of an image, M_e, about its symmetrical axis produces an image, M_e', which is approximately identical to M_e. Therefore the line of symmetry of an image can be found by searching for the orientation that maximises the cross-correlation between the original image and a rotated mirror image of the original image [14].

To find the line of symmetry, the image, M_e, is first reflected about y-axis to produce a mirror image, M_e'. If the line of symmetry of M_e is orientated Θ degrees from the vertical, then the line of symmetry of M_e' will be orientated -Θ degrees from vertical. Therefore M_e' would have to be rotated by 2Θ degrees for it to have the best cross-correlation with M_e.

To search for the best orientation, Θ, of the line of symmetry, M_e' is rotated about the centre of the image and the maximum correlation value, $C(\Theta_j)$, form the cross-correlation between M_e and M_e' for each Θ_j is recorded. The cross-correlation is performed in the frequency domain, as shown in (3) [14], using the fast Fourier transform (FFT) for improved computational efficiency.

$$C(\theta_j) = max\{F^{-1}(F^*(M_e)rot(2\theta_j,(F(M_e'))))\} \quad (3)$$

Let Θ_B, be the angle of the line of symmetry and its optimum value is given by the following equation:

$$\theta_B = \{\theta_j : C(\theta_j) = max\{C(\theta_j)\}\} \quad (4)$$

After the angle of the line of symmetry is determined, the image is then rotated by -Θ_B, such that the line of symmetry is in a vertical position. The horizontal translation offset, t_h, is then evaluated using the phase correlation method [17] and is adjusted accordingly.

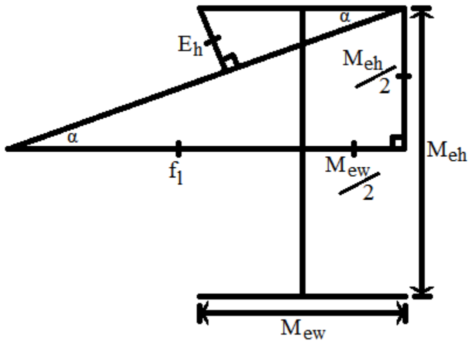

Figure 4. The ellipse height, E_h, is found using the Pythagorean trigonometric identity.

D. Tilt Correction

Due to the lizards being live animals, their posture cannot be easily manipulated. Tilt correction is required before symmetry measurement. Refer to Fig. 3, an affine transformation has to be calculated based on the angle of tilt first. The properties of an ellipse are used to estimate the changes in width and height of the image based on the angle of tilt. The width of the ellipse, E_w, is equal to the width of the image, M_{ew}, and the height of the ellipse, E_h, is found with the Pythagorean trigonometric identity shown in Fig. 4 as follows:

$$E_h = M_{ew} cos\alpha \quad (3)$$

$$\alpha = \tan^{-1}\left(\frac{M_{eh}/2}{f_l + M_{ew}/2}\right) \quad (4)$$

where M_{eh} is the height of the image and f_l is the focal length of the camera. The height of the ellipse is determined by the distance from which the image is viewed, and the distance from that scene to the sensor is the focal length. Once the width and the height of the ellipse are known, the radius, E_r, can be determined at each angle, Θ, of tilt using the following equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad (5)$$

where

$$a = \frac{E_w}{2}$$

and,

$$b = \frac{E_h}{2}$$

Using the polar coordinates $x = r(\Theta)\cos\Theta$ and $y = r(\Theta)\sin\Theta$ and substituting them into (5) gives the equation for the radius of the ellipse, E_r, as shown below:

$$E_r(\theta) = \frac{ab}{\sqrt{\{(b\cos\theta)^2 + (a\sin\theta)^2\}}} \quad (6)$$

The change in width, W_c, and height, H_c, needed for the affine transformation at each angle can be found using the Pythagorean trigonometric identity, as the radius of the ellipse is the hypotenuse, W_c is the adjacent edge, and H_c is the opposite edge. The equations for W_c and H_c are then given as follows:

$$W_c = \left(\frac{M_{ew}}{2}\right) - E_r\cos\theta \quad (7)$$

$$H_c = E_r\sin\theta \quad (8)$$

To determine the tilt angle for correction, the image is tilted through various degrees. The image is divided into its left and right halves, M_L and M_R respectively. The left half of the image is mirrored and then cross-correlated with the right half and the maximum correlation value for each angle is recorded. The angle with the highest correlation value is deemed as the angle for tilt correction. The process described above is tilt correction for the horizontal plane and is then repeated similarly for the vertical plane. An example of tilt correction is shown in Fig. 5, where it can be seen in Fig. 5 (b) that that scale pattern appears to be flatter.

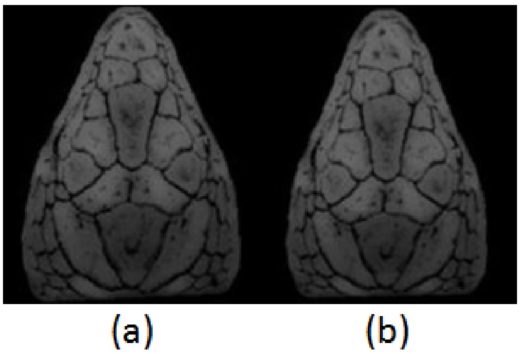

Figure 5. (a) The input image, (b) The tilt corrected image.

E. Edge Detection and Morphological Filtering

Prior to symmetry measurement, edge detection is performed on the pattern enhanced image produced by the enhancement methods described previously to avoid missing weak edges which is important to improve the robustness in the symmetry measurement. Edge detection is used to extract the scale pattern of each lizard to a binary image so that the symmetry rating can be evaluated. The Canny [15], Laplacian, and Sobel edge detection methods were each assessed and it was found through visual inspection that the Canny method provided best edge detection with less unwanted features in the scale pattern. Fig. 6 (a) and (b) show the outputs after edge detection is performed using the Canny method on the original and enhanced image respectively. It is obvious that major scale patterns are preserved in Fig 6 (b) while unwanted features are removed.

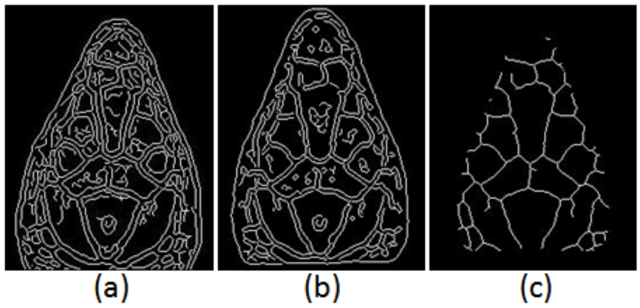

Figure 6. (a) The Canny edge detection output on the original image, (b) the Canny edge detection output on the enhanced image, (c) The final binary image output, M_{10}.

In addition to edge detection, a series of morphological operations are used to strengthen the connecting edges of the scale pattern and remove unwanted features in order to produce a binary image that will give a robust symmetry rating. Dilation, '⊕', is first performed on the edge image, M_1, given by (9), to connect broken edges.

$$M_2 = M_1 \oplus A^s, \text{ where}$$
$$A^s = \{010; 111; 010\} \quad (9)$$

To remove unwanted features from M_2, any connected components with 4-edge connectivity are found, and any components with a size less than the mean size of all the connected components are considered as unwanted features and will be removed to produce, M_3. A logical 'and' is then performed in (10) on the resulting image and the original edge image, M_1, to recover the original edge detection image without the unwanted features, M_4.

$$M_4 = M_3 \bullet M_1 \quad (10)$$

A morphological closing is performed on M_4 in (11) to connect the edges and the 8-edge connected components are found, any components with a size less than the mean size of all the connected components are removed. This is done so that any unwanted features still remaining are removed to produce M_6. A logical 'and' is then performed with the original edge image, M_1, to recover the original edge detection image with all the unwanted features removed to give, M_7 as follows:

$$M_5 = (M_4 \oplus A^s)\Theta A \quad (11)$$

$$S_7 = S_6 \bullet S_1 \quad (12)$$

Another closing is then performed with a larger structuring element in (13) to ensure the edges that form the scale pattern are all connected. A morphological thinning operation, T, [16] is then applied to reduce line thickness in M_8 to a single pixel width producing the image, M_9.

$$M_8 = (M_7 \oplus B^s)\Theta B, \text{ where}$$
$$B^s = \{11111; 11111; 11111; 11111; 11111\} \quad (13)$$
$$M_9 = T\{M_8\} \quad (14)$$

As the scale pattern of the lizard is the major feature for symmetry measurement, the outlier of the lizard has to be removed prior to symmetry measurement using an image screen. A thresholded image, M_o, is first produced by thresholding the original greyscale image with any pixel value greater than zero. A logical 'and' operation is applied to the mirror image of M_o, M_o', with M_o to create a perfectly symmetric image template. This template is then morphologically eroded to produce an image screen, M_s, to exclude the shadow regions and the lizard outlier as follows.

$$M_s = (M_o \bullet M_o{'})\Theta A^s \quad (15)$$

The image screen is then applied to M_9 for the extraction of the scale pattern using (15) as shown in Fig. 6 (c).

$$M_{10} = M_9 \bullet M_s \quad (16)$$

The image symmetry rating is based on the correlation between the left and right half of the image, M_L and M_R, respectively. The two halves of the image are defined using the line of symmetry found in section C as the dividing plane. To maximise the range of the rating, the two image halves are first aligned using phase correlation method [17].

F. Symmetry Rating

To calculate the final symmetry rating, the normalized correlation between the left and right image halves, namely M_L and M_R, is evaluated by (17) to be used as a symmetry index. A lower correlation value between the left and right images implies greater asymmetry of the lizard. For perfect symmetry, the normalized correlation equation (17) will give a value of unity.

$$S = \frac{\sum_{x,y}[M_L(x,y) - \overline{M_L}][M_R(x,y) - \overline{M_R}]}{\sqrt{\sum_{x,y}[M_L(x,y) - \overline{M_L}]^2 \sum_{x,y}[M_R(x,y) - \overline{M_R}]^2}} \quad (17)$$

where $\overline{M_L}$ and $\overline{M_R}$ are the mean values of the left and right image halves respectively.

III. RESULTS

Samples of the images used for the image symmetry measurement are shown in Fig. 7, they are ranked in order from least symmetric to most symmetric. Included amongst these samples are multiple images of the same lizard. Table I gives the symmetry measurement for each lizard. As an example in Table I, images (j) and (k) having the same code 2224 are different images of the same lizard coded 2224. Whilst there are other methods for measuring asymmetry which involve the measurement of linear lengths of bilateral characters, such as leg length, or other characters such as the count of head scales, there are no comparable techniques using the actual lizard image for asymmetry measurement. As other techniques being used by the biologists are measurements based on the count or linear lengths of bilateral characters, they do not always agree with visual assessment. For the symmetry measurement using different images of the same lizard, the largest standard deviation of errors from the values in Table II is only 0.0060. The proposed method has also been verified visually by a number of experts by comparing the images with their symmetric indices to confirm that the image symmetry measurement has good consistency with visual assessment.

IV. CONCLUSION

Image asymmetry measurement inferred by a symmetry index for the study of endangered Pygmy Bluetongue Lizard has been developed and found to have very good consistency with visual assessment for the endangered Pygmy Bluetongue Lizards in our experiments. This measurement will be used for the study of how asymmetry in lizards correlates to its health and chance of survival in the wild. Future work will include a quality index for the exclusion of poor quality images in order to give an indication of the accuracy and to improve the robustness of asymmetry measurement.

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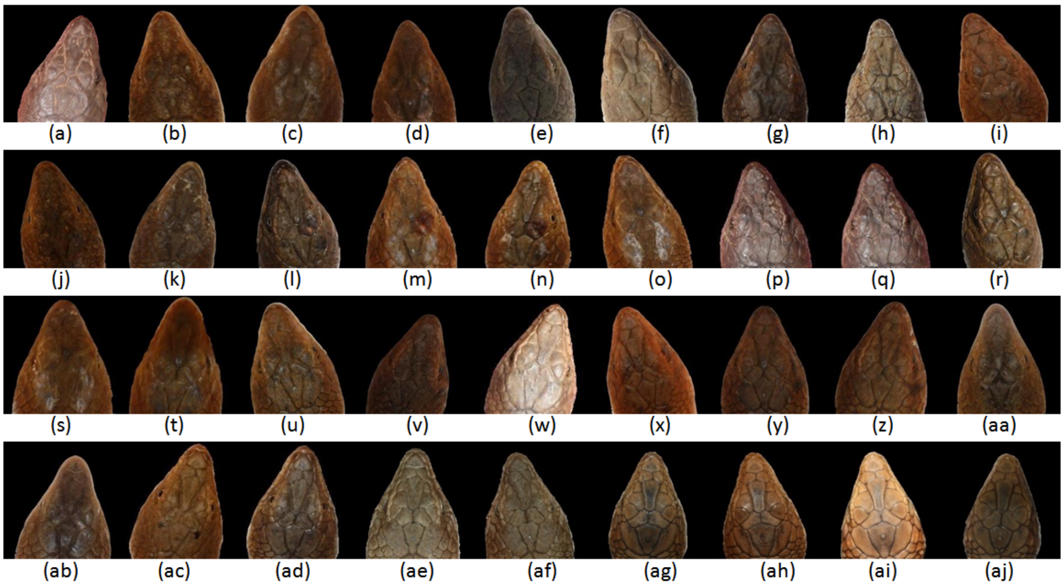

Figure 7. A sample of the lizard images used for image symmetry measurement.

TABLE I. THE SYMMETRY MEASUREMENTS FOR THE IMAGES SHOWN IN FIG. 7.

Image	11067 (a)	11071 (b)	21075 (c)	21075 (d)	11071 (e)	21075 (f)	21062 (g)	21062 (h)	21062 (i)	2224 (j)	2224 (k)	11072 (l)
Symmetry	0.1813	0.2136	0.2142	0.2180	0.2183	0.2199	0.2502	0.2530	0.2617	0.2801	0.2833	0.2910
Image	11072 (m)	11072 (n)	11070 (o)	1183 (p)	1183 (q)	11070 (r)	11070 (s)	11070 (t)	11069 (u)	11070 (v)	11069 (w)	21063 (x)
Symmetry	0.2912	0.2969	0.3016	0.3040	0.3047	0.3051	0.3091	0.3092	0.3093	0.3133	0.3135	0.3310
Image	21063 (y)	21063 (z)	21065 (aa)	21065 (ab)	150 (ac)	150 (ad)	21007 (ae)	21007 (af)	21006 (ag)	21004 (ah)	21015 (ai)	2701 (aj)
Symmetry	0.3368	0.3395	0.3692	0.3715	0.4910	0.4962	0.5275	0.5322	0.6896	0.7223	0.8246	0.9010

TABLE II. THE MEAN AND STANDARD DEVIATIONS FOR DIFFERENT IMAGES OF THE SAME LIZARD.

Image Group	11071	21062	21075	2224	11072	1183	11070	11069	21063	21065	150	21007
Mean	0.2160	0.2550	0.2817	0.2817	0.2930	0.3044	0.3077	0.3114	0.3358	0.3704	0.4936	0.5299
Standard Deviation	0.0033	0.0060	0.0029	0.0023	0.0034	0.0005	0.0045	0.0030	0.0043	0.0016	0.0037	0.0033