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A New 2D Pulse Domain Transform (PDT) Feature Extraction Technique for Fingerprint Biometrics

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Abstract: Feature extraction is a technique to extract derived value which is informative and non-redundant. There are many techniques have been reported in the literature on its usage application on signal and image. Some of the common techniques of feature extraction are Fast Fourier Transform, Wavelet Transform, Histogram of Oriented Gradients (HOG), Speeded Up Robust Features (SURF), Local Binary Patterns (LBP), Haar Wavelets, and Color Histograms. Recently, a new feature extraction technique based on Pulse Width Modulation (PWM) has been proposed. PWM is widely used for speed control technique and for the application in feature extraction. PDT is a feature extraction technique that derived from PWM. Initially, PDT applies on electrocardiogram (ECG) signal and draw out a non-invertible output. This output is presented as pulse waveform which is generated by the amplitude's comparison of ECG signal with a periodic triangular waveform to get the intersection points. The time location of the intersection points are then used to be the transition state for output pulse to raise, fall or preserve the status quo. Since the PDT concept is only applied to 1D signal, it is interesting if the technique can be extending to 2D signal. This work presents a 2D PDT feature extraction technique. The concept of 2D PDT also based on the principle of PWM which is to process the incoming image (2D signal) with the aid of a 2D triangular waveform to form an output of 2D pulse waveform. Furthermore, the 2D triangular waveform is set up based on the desired threshold for its frequency and amplitude, namely, these thresholds are modulated in accordance with the size of the image. Afterward, the superposition process is proceeding between the processed image and modulated 2D triangular waveform to generate the intersection points for further forming of the output of 2D pulse waveform. The technique is then tested on fingerprint biometric and shows its ability to generate unique feature from the fingerprint images. This uniqueness takes shape caused by the inconstancy of the frequency and amplitude of pulse waveform. More than that, it able to provide a quite high accuracy rate and Area Under the Receiver Operating Characteristic curve (AUROC or AUC) reading. The accuracy is about 87% on average and the AUC is about 0.86 on average. In accordance with the result, 2D PDT is proven that it can perform as a good feature extraction technique with no less favorable than other outstanding techniques.

1. INTRODUCTION

Signal is the physical quantity that carries information with a broad meaning in all the domains of knowledge gathering. If a signal does not have meaning with respect to a specific application, it is considered as an unwanted signal or noise, (Apurba, *et. al,* 2015). Therefore, signal is necessary to process to extract its features so that it can be displayed, analyzed, classified, or converted to another type of signal that may be of use. These features play a very important role in signal processing as it is the information which can reflect the nature of the signal. As to feature extraction, it is a process of dimensionality reduction that efficiently represents interesting parts of a signal. In the matter of 2D signal (image), it is generally too large to be processed and suspected to be redundant (much data, but not much information), so it is a burden to a system in term of memory and time spent, (Wiki/Feature Extraction, et. al). Thus, feature extraction technique assist to transform an image into a reduced set of features which in the manner of informative and non-redundant to reduce the burden of memory and time spent.

There are a number of signal transformation techniques that commonly used in 1D and 2D plane such as Fourier Transform (FT), Wavelet Transform (WT), and so on. However, it is found that only PDT applied in 1D plane and so far has not stepped into 2D plane. Thus, it is believed that this transformation technique, PDT has high research value and vast potential for future development. Then, the idea is carried out to extend to 2D PDT from the 1D manner. With this new technique, it would contribute to various fields especially in security authentication system due to its function of non-invertible.

Fingerprint biometrics is chosen as the first and ideal 2D signal to be used in measuring the potency of 2D PDT. This is due to biometric characteristics are universal, unique, permanent, and measurable. Yet, fingerprint is the most popular physiological characteristic used for authentication and authorization in biometric system. Moreover, fingerprint is the most convenient, reliable, robust and widely used form, since everybody holds unique pattern of fingerprints, even identical twins have different fingerprints, (Sadi, *et. al,* 2011), (Tariq, *et. al,* 2011), (Jain, *et. al,* 2004). The uniqueness of one's fingerprint remains same throughout the lifetime and do not vary much over time (Nasiri, *et. al,* 2015).

A fingerprint is basically characterized by a pattern of interleaved ridges and valleys present on the surface of fingertip. Ridge refer to the protruding line that form the fingerprint pattern and shown as dark line in fingerprint. Valley refer to the concave line that form

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the spaces between the ridges and shown as bright line in fingerprint **(Fig 1).** (Kaur, *et. al,* 2010)

Fig.1. Example of Fingerprint (Kaur, *et. al,* 2010)

2. BACKGROUND

PAT is the primary concept of PDT. It is a method of features extraction that generally applicable to any 1D signal (Saifi, *et. al,* 2014), (Saifi, *et. al,* 2015). Even so, but it is mainly applied on biometric authentication system with electrocardiogram (ECG) as its investigated signal (Saifi, *et. al,* 2014), (Saifi, *et. al,* 2011). Yet, PAT is a non-invertible transformation technique that avoiding invertibility attacks (such as recovery of the signal) to ensure the complete security of the original ECG signal. This additional security ascribe to its principle that does not require any specific kernel function for signal transformation. There out, it is different from most widely used integral transformation techniques such as Fourier or Wavelet transforms (Saifi, *et. al,* 2014).

The operation of the PAT is to decompose an ECG signal into a finite set of pulse active features based on a series of harmonically related periodic triangular waveforms. In other word, it compares the ECG signal (investigated signal) with a triangular waveform signal (modulating signal) to generate output pulse waveform (as shown in **(Fig. 2)** (Saifi, *et. al,* 2014), (Saifi, *et. al,* 2011). This comparison is based on the amplitude of both ECG and triangular waveform signal to yield the intersection points for forming of output pulse waveform. An intersection point refer to both signals are in the same amplitude on specific intersection location time. Also, it is a transition state for output pulse to rise or fall according to that particular intersection point. For the rest lead the output pulses to preserve the status quo, no matter the amplitude of ECG signal is more than (in high state) or less than (in low state) the amplitude of triangular waveform signal (Saifi, *et. al,* 2011).

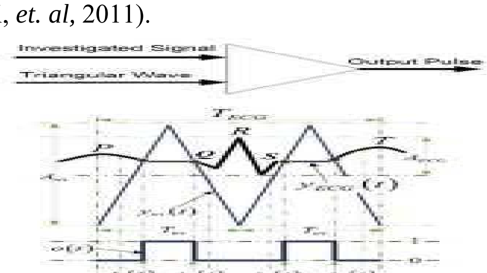

Fig.2. Example of PAT (Saifi, *et. al,* 2011)

3. MATERIAL AND METHODS

2D PDT is essentially further developed from its 1D manner known as PAT which is originated from the principle of PWM. Hereupon, 2D PDT is designed to process the incoming image (2D signal) with the aid of a 2D triangular waveform to form an output of 2D pulse waveform. However, there is difference in the output aspect **(Fig. 3).** For 1D PDT, the output pulse waveform formed up in same amplitude but different time duration. For 2D PDT, it able to generate the output pulse waveform to be inconstancy on its frequency and amplitude because it would increase its uniqueness and distinctiveness to deter spoofing.

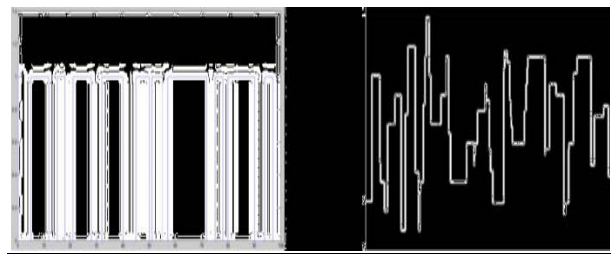

Fig.3. Example of Output Pulse Waveform

In this project, there are 30 samples of fingerprint image collected from students at University Kuala Lumpur (UniKL) - British Malaysian Institute (BMI). The fingerprint of first finger is considered and adopted instead of thumb due to the private and confidential sake. The fingerprint is taken twice on the same finger for a student because of different pressure and positioning might influence the result of matching. Then, these fingerprint images of same finger are aligned manually before get into feature extraction to avoid the effect of position displacement.

There are hundreds of combinations that can be used to perform 2D PDT in this research work. These combinations are formed up based on certain criteria such as the thickness of fingerprint, type of triangular waveform, number of cycles of triangular waveform, thickness of triangular waveform, thickness of the output pulse waveform and matching method. In fact, it is set up to measure the potency of all these combinations in order to acquire the best combination which able to generate the best matching score and AUC reading among them.

Yet, all these criteria are blended in with the process of feature extraction which is comprised by pre-processing of fingerprint, 2D triangular waveform making, intersection points finding, output of 2D pulse waveform forming and matching score generating. Therefore, it is not only discussing the process of feature extraction in the following, but also those that related to the criteria and the best choice of the combinations.

3.1 Pre-processing of Fingerprint

The fingerprint is first processed with Histogram Equalization to enhance the contrast of fingerprint. Then follow by Median Filter to reduce the noise of fingerprint **(Fig 4).** These processes would aid to obtain better quality of fingerprint image. So that, it would bring benefit to the binarization process in term of preventing the ridge lines go vanish and break.

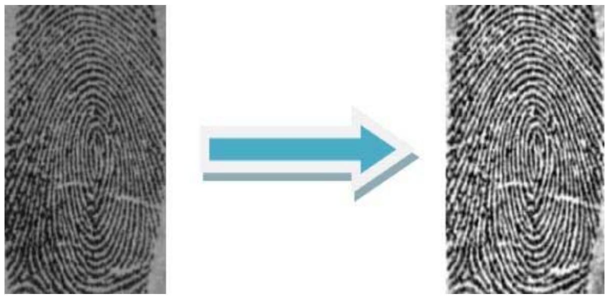

Fig.4. Process of Histogram Equalization and Median Filter

Even so, the normal binarization process still has not been up to desired. Then, the threes hold in gbinarization process **(Fig 5).** is further apply and proceeds with certain alteration. A non-overlapping 10 x 10 matrix is employed over the fingerprint image to obtain its own mean value as the threshold value for its own internal 100 intensity values. These intensities of 100 internal pixels in the 10 x 10 matrix are then converted to binary value by referring to the threshold (mean value). For those less than the threshold will convert to 0, and those equal to or more than the threshold will convert to 1. This 10 x 10 matrix is adopted based on the maximum width of the ridge and valley among the collected fingerprint and the size of the fingerprint image.

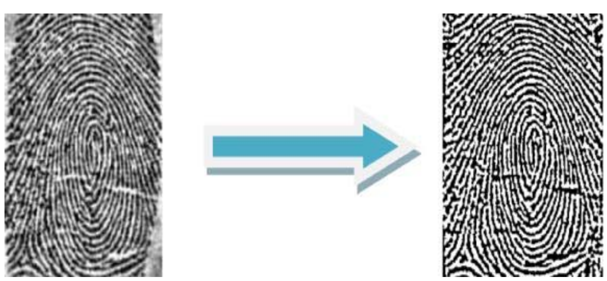

Fig.5. Process of Binarization

The binarized image is then thinned to reduce the thickness of ridges to one pixel width for precise location of features extraction as thinning does not change the location and patterning of fingerprint structure compared to the original fingerprint **(Fig 6).**

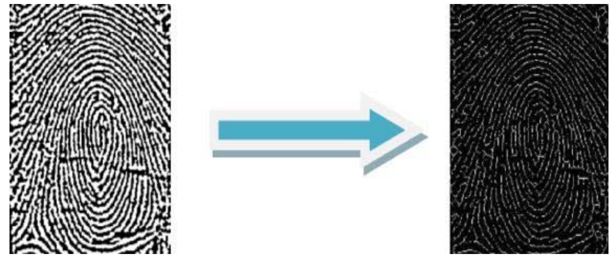

Fig.6. Process of Thinning

Then, a mask of the fingerprint is made to filter the redundant ridges around the boundary in fingerprint image (as shown in **(Fig.7)).** So that it would not bring in any unnecessary ridge lines that might further influence the result of matching.

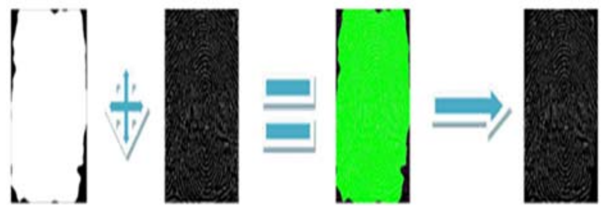

Fig.7. Mask Filter

The thickness of fingerprint is a criterion of the combinations. It will choose either to be thin or thick fingerprint. The thin fingerprint is referring to thickness of ridges in 1 pixel thick, while the thick fingerprint is referring to the binarized fingerprint. According to the result analysis, the best choice of the thickness of fingerprint among the hundreds of combinations is the thinned fingerprint.

3.2 2D Triangular Waveform Making

2D triangular waveform is an important modulating signal for 2D PDT. By the equation (1) and (2), a triangular waveform can be formed up and used to assist the process of intersection points finding. These equations are designed for 2D plane, so there are some conditions need to be avoided. One of them is all the pixels are counted in round number. Yet, the arrays need to start with coordinate of 1 and onward for horizontal and vertical array. This means that no 0 and negative number for a 2D array. Therefore, based upon these conditions, it is necessary to made accommodating change on the equation (1) and (2) to eligible for the principle of pixel.

$$Y = 1 + ROUND[(Y_{Max} - 1) * ABS\left(\left(\frac{MOD(x_i,c)*2}{c}\right) - 1\right)] \quad (1)$$

$$C = ROUND = \frac{X_{Max}}{Number\ 0f\ Cycles} \quad (2)$$

For i=1,…….,X_{max}. Y is the coordinate position of row. $Y_{max}$is the length of row of an image. $X_{max}$is the length of column of an image. C is the number of pixels per cycle.

There are some criteria of combinations that related to 2D triangular waveform such as the type, thickness, and number of cycles of a triangular waveform. The following are discussing the optional combinations for a 2D triangular waveform.

For the type of 2D triangular waveform, there are 2 basic types of the lines that can be used to form the triangular waveform. One of the line's types is continuous type also called linear type and the other one is discontinuous type also called dot type (as shown in Figure 8). From the equation (1) and (2), the triangular waveform is originally generated in dot line. For the linear type, it just connects all the dots in accord with the pattern of triangular waveform.

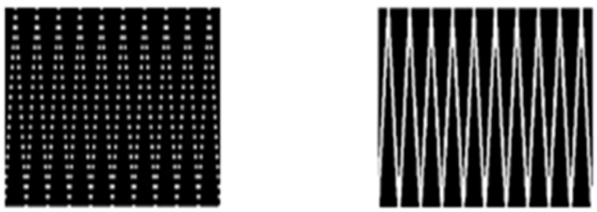

Fig.8. Example of Dot Type and Line Type

For the number of cycles, the more the cycles of the waveform will add in unnecessary points to increase the complexity of matching. In contrast, the less the cycles of waveform will loss the important points and increase the danger of spoofing attack. Therefore, according to the size of image, 10 cycles is selected and accepted as the better maximum number of cycles to form a triangular waveform while 2 cycles is the better minimum number of cycles. Then, a 6 cycles is adopted as the middle number between them **(Fig 9).**

Fig.9. Example of 2 Cycles, 6 Cycles and 10 Cycles Oscillation

For thickness of 2D triangular waveform, it will take as the width of coverage of the fingerprint's ridge lines. There are 3 coverage patterns such as 1 pixel coverage, 9 pixels coverage and 25 pixels coverage (as shown in Figure 10). For the case of 1 pixel, it takes 0 steps to expand the coverage to top and bottom, left and right (1 x 1 pixel coverage). For the case of 9 pixels, it expands 1 pixel to 4 directions to form 3 x 3 pixels coverage and 2 pixels expanding around a pixel of the waveform line for the case of 25 pixels (5 x 5 pixels coverage).

Fig.10. Example of 1 Pixel, 9 Pixels and 25 Pixels Case

From the result analysis, the best choice for a 2D triangular waveform among the hundreds of combinations is the triangular waveform in discontinuous type (dot type) with 6 cycles of oscillation and thickness of 25 pixels **(Fig 11).**

Fig.11.The Best Choice of 2D Triangular Waveform

3.3 Intersection Points Finding

The superposition process is proceeding between the processed images and modulated 2D triangular waveform to generate the intersection points **(Fig 12)** for further forming of the output of 2D pulse waveform. The triangular waveform is not only take oscillation cycles from left to right but also from top to bottom **(Fig 13)** for more protection and confidentiality sake.

Fig.12. Example of Intersection Points

Fig.13. Example of Oscillation Cycle of Triangular Waveform

As the other direction can form another meritorious set of intersection points. This means that it able to provide 2 distinct outputs with a same fingerprint image. Since, they are both unique and can be the mainstay to form output pulse waveform. They are then combining in side to side become one. However, the triangular waveform oscillated from top to bottom has to rotate 90 degree to left in order to avoid the vertical lines of output pulse waveform stick together. So, in the same way, the fingerprint images will do to cohere with the pattern of triangular waveform **(Fig 14).** For this process is straightforward and do not have any criteria of combinations get involved.

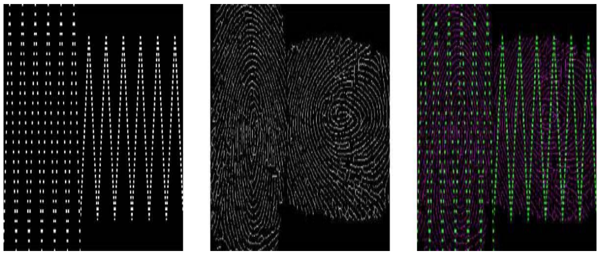

Fig.14. Example of Combined 2D Triangular Waveform

3.4 Output of 2D Pulse Waveform Forming

2D output pulse waveform is generated by connecting each of the intersection points from left most to the right most across the 2D plane. There is a criterion of combinations get involved in this output pulse waveform and it is related to its thickness. Same as above, the thickness is counting on the 4 directions of expanding in length of 0, 1 and 2 to obtain the width of 1 pixel, 9 pixels and 25 pixels thick for the output pulse waveform **(Fig.15).** According to the result analysis, the best choice of the thickness of output pulse waveform among the hundreds of combinations is 1 pixel thick.

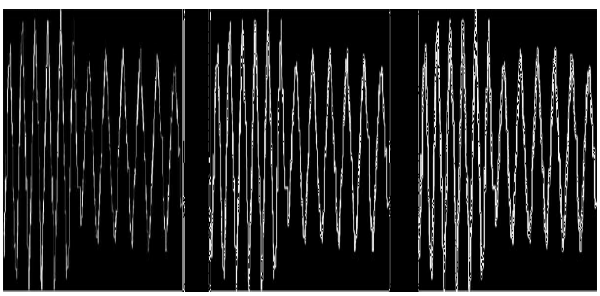

Fig.15. Example of 1 Pixel, 9 Pixels and 25 Pixels Case

3.5 Matching Score Generating

The matching method is a criterion of the combinations. It will choose either method S_1 (3) or S_2 (4). $S_1$is the method of computing the 2D correlation coefficient between input set and template set where both images are in the same size to obtain the matching score from 0 to 1 **(Fig. 16).** While, S_2 is the basic way of computing the matching score which will provide scoring from 0 to 1. According to the result analysis, the best choice of the matching method among the hundreds of combinations is S_1

$$S_1 = \frac{\Sigma_x \Sigma_y \left(I_{xy} - I_{mean}\right)\left(T_{xy} - T_{mean}\right)}{\left(\Sigma_x \Sigma_y \left(I_{xy} - I_{mean}\right)^2\right)\left(\left(\Sigma_x \Sigma_y \left(T_{xy} - T_{mean}\right)^2\right.} \quad (3)$$

$$S_2 = \Sigma_x \Sigma_y \ = \frac{I_{xy} \& T_{xy}}{I_{xy} \mid\mid T_{xy}} \quad (4)$$

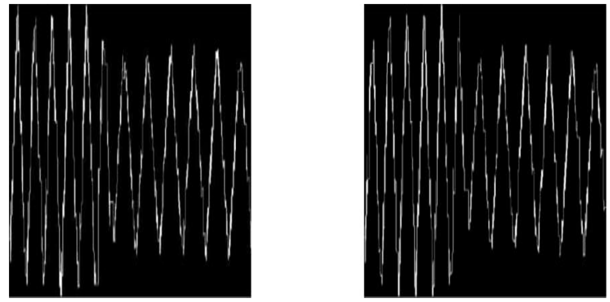

Fig.16. Example of 2 Output Pulse Waveform of a Finger with Twice Print

4. <u>RESULTS AND DISCUSSION</u>

In this experiment, there are 2 sets of fingerprint images per person are collected from 30 students. These total 60 fingerprint images are divided into 2 groups which are Group A and Group B. Group A is the 1st set printed fingerprint images of 30 students while Group B is the 2nd set. These 2 groups are then take turn to be the investigation set and template set. When Group A is the investigation set, Group B will be the template set, and it is called Group AB. When Group B is the investigation set, Group A will be the template set, it is Group BA. So, all the hundreds of combinations are processed 2 times to obtain the matching score and AUC reading in different perspective for precise result analysis. Table 1 is shown about the range of matching rate and AUC rate among the hundreds of combinations. Hereinafter, the matching score is treated as the averaging percentage of 30 students which had gone through the equation (3) or (4). It will further expand in the following.

Table 1: Range of Result of hundreds of Combinations

	Group AB		**Group BA**	
	Matching Rate	AUC Rate	Matching Rate	AUC Rate
S1, Equation (3)	23% - 83%	0.27 - 0.85	20% - 90%	0.26 - 0.86
S2, Equation (4)	26% – 83%	0.26 - 0.85	23% – 90%	0.26 - 0.86

From **(Table 1),** although it is shown that Group BA able to work out better matching rate and AUC rate when compare with Group AB, but in fact, there is no discrepancy in this experiment. This is because of the experiment is focused on the conformity between the best combination in Group AB and the Group BA. This means that, the same combination in different group must work out the highest matching score and AUC reading. For instance, the best combination in Group AB must have the matching score of 83.33333333% and AUC reading of 0.856666667, and the same combination in Group BA must be the best therein with matching score of 90% and AUC reading of 0.862222222.

Table 2: The Better Options among the Hundreds of Combinations of Group AB

A	B	C	D	E	F	G	H	I
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S1	AB	83.33333333%	0.856666667
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S2	AB	83.33333333%	0.856666667
Thin	Linear	6 cycles	1x1 pixel	1x1 pixel	S1	AB	83.33333333%	0.832222222
Thin	Linear	6 cycles	1x1 pixel	1x1 pixel	S2	AB	83.33333333%	0.828888889
Thin	Dot	10 cycles	5x5 pixels	1x1 pixel	S1	AB	83.33333333%	0.813333333
Thick	Dot	6 cycles	3x3 pixels	1x1 pixel	S1	AB	83.33333333%	0.768888889

A. Thickness of Fingerprint
B. Type of Triangular Waveform
C. Number of Cycle of Triangular Waveform
D. Thickness of Triangular Waveform
E. Thickness of Output Pulse Waveform
F. Matching Method
G. Group
H. Matching Score
I. AUC Reading

Table 3: The Better Options among the Hundreds of Combinations of Group BA

A	B	C	D	E	F	G	H	I
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S1	BA	90%	0.862222222
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S2	BA	90%	0.862222222
Thin	Linear	6 cycles	1x1 pixel	1x1 pixel	S1	BA	90%	0.827777778
Thin	Linear	6 cycles	1x1 pixel	1x1 pixel	S2	BA	90%	0.827777778
Thin	Dot	6 cycles	5x5 pixels	3x3 pixels	S1	BA	90%	0.797777778
Thin	Dot	6 cycles	5x5 pixels	3x3 pixels	S2	BA	90%	0.787777778

Moreover, **(Table 2)** and **(Table 3)** shown that several combinations able to produce the highest matching score with different AUC reading in Group AB and Group BA. Unfortunately, there is also repeated highest AUC reading among the combinations with the highest matching score. Thereupon, the combinations of the 2 highest scores (matching score and AUC reading) indicated that they are same in all criteria except matching method. Therefore, it is necessary to go in detail for the scoring of equation S1 (3) and equation S2 (4) in Group AB and Group BA.

Table 4: Scoring of S1 and S2

Group	**True**					**Closest**			**Total**
	0.2	0.3	0.4	0.5	0.6	0.2	0.3	0.4	
AB-S1			7	18	5			30	
AB-S2	2	16	11	1			30		
BA-S1			7	18	5		1	29	
BA-S2	2	16	11	1		1	29		
Group	**Gaps**			**Overview**					
	0	0.1	X	0.2	0.3	0.4	0.5	0.6	
AB-S1	15	10	5			#	18	5	23
AB-S2	17	8	5	2	#	11	1		14
BA-S1	17	10	3		*	#	18	5	23
BA-S2	17	10	3	#	#	11	1		12

In the process of testing the potency of hundreds of combinations, it uses averaging method to obtain the percentage of matching score. For instance, an investigation fingerprint in Group A is first compare against 30 template fingerprints in Group B with the equation (3), and then the highest score will seek out from these 30 scorings. If the fingerprint of template with highest score and the fingerprint of investigation are belonged to the same person, then it is count as match case and gives the matching status with value of 1 else it is a non-match case and takes as 0. This step would perform for 30 students in Group A to obtain 30 values of matching status. Then, the average computation of 30 matching status will perform to generate the percentage of matching score for a combination.

The True in **(Table 4)** records the score of comparing of the same person. For the Closest, it refers to the 2nd highest score for match case and the highest score for non-match case. The Gaps is about the different between the True and Closest and it will ignore those non-match cases. For the Overview, it is the fusion of True and Closest. The Total is referring to the sum of Overview. Yet, the entire numerals in Table 4 are the number of times of the scorings under its own range for the comparing results. For instance, case AB-S1 under True, it has 7 times in range about score of 0.4, 18 times in range about score of 0.5 and 5 times in range about score of 0.6.

Next, the determination of equation will not count on the Gaps as it is given the same maximum gap about 0.1 for all the groups in **(Table 4)** Besides, it is obvious that Group AB and Group BA with equation S1 (3) able to produce higher scoring when compare to equation S2 (4). However, it is not the main key to define the best equation. The main point is the sum of the number of times for the scoring under True that greater than the maximum scoring under Closest. For instance, in group AB-S1, the maximum scoring under Closest is 0.4, so the scoring of 0.5 and above which under True are taken count to be the sum for decision making. Therefore, the equation S1 (3) with the higher sum value is considered and adopted as the best matching method. The symbol of # and * represent the cancelled items.

Finally, the best combination among the hundreds of combinations is formed by the criteria of thin fingerprint, dot type triangular waveform with thickness of 5 x 5 pixels in 6 cycles oscillation, output pulse waveform with thickness of 1 x 1 pixel and equation S1 (3) and it is called primary combination. Even Group AB and Group BA proceed with the same method, but they are produced difference results as shown in Figure 17. This is because of the swapping between Group A and Group B to be the investigation set and template set. Moreover, there is a combination almost on a par with the best combination. It is formed by the criteria of thick fingerprint, dot type triangular waveform with thickness of 1 x 1 pixels in 6 cycles oscillation, output pulse waveform with thickness of 1 x 1 pixel and equation S1 (3) and it is secondary combination.

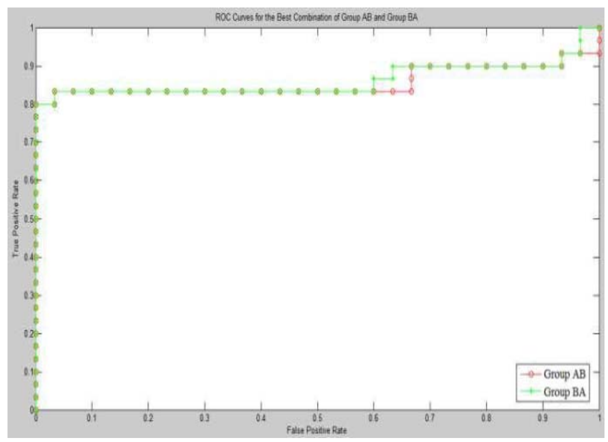

Fig.17. ROC Curve for the Best Combination

Table 5: Proximate Combinations

A	B	C	D	E	F	G	H	I	Total	Gaps			
										0	0.1	0.2	0.3
Thin	Dot	6 Cycles	5×5 pixels	1×1 pixels	S1	AB	83.33333333	0.8566 66667	23	15	10		
Thick	Dot	6 Cycles	1×1 pixels	1×1 pixels	S1	AB	76.66666667	0.78	21	9	7	7	
Thin	Dot	6 Cycles	5×5 pixels	1×1 pixels	S1	BA	90	0.8622 22222	23	17	10		
Thick	Thin	6 Cycles	1×1 pixels	1×1 pixels	S1	BA	80	0.8055 55556	21	8	10	5	1

In certain respect, in fact, secondary combination performed better than primary combination as it has wider range of the gaps and be the 2nd highest sum of True Score. However, it is unable to be the best because it has lower matching score and AUC reading which 9% on average is lower than the primary combination **(Table 5).** From **(Table 6 and Table 7),** the secondary combination still consider keeping lower matching score and AUC reading when compare to others. But even so, based on the wider range of gaps and the 2nd highest sum value, it is still accepted as the 2nd best combination among all. **(Fig 18)** show the ROC curve for primary and secondary combination of Group AB and Group BA. **(Fig. 19 and Fig. 20)** able to clearly differentiate the primary and secondary combination of Group AB and Group BA. Based on these data, there is no doubt that the primary combination is the best choice for 2D PDT.

Table 6: The Top Combinations in Group AB

A	B	C	D	E	F	G	H	I	Total
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S1	AB	83.33333333	0.856666667	23
Thick	Dot	6 cycles	1x1 pixel	1x1 pixel	S1	AB	76.66666667	0.78	21
Thin	Dot	10 cycles	5x5 pixels	1x1 pixel	S1	AB	83.33333333	0.813333333	14
Thick	Dot	6 cycles	3x3 pixels	1x1 pixel	S1	AB	83.33333333	0.768888889	14
Thin	Linear	6 cycles	1 x 1 pixel	1 x 1 pixel	S1	AB	83.33333333	0.832222222	8

A. Thickness of Fingerprint
B. Type of Triangular Waveform
C. Number of Cycle of Triangular Waveform
D. Thickness of Triangular Waveform
E. Thickness of Output Pulse Waveform
F. Matching Method
G. Group
H. Matching Score
I. AUC Reading

Table 7: The Top Combinations in Group BA

A	B	C	D	E	F	G	H	I	Total
Thin	Dot	6 cycles	5x5 pixels	1x1 pixel	S1	BA	90	0.862222222	23
Thick	Dot	6 cycles	1x1 pixel	1x1 pixel	S1	BA	80	0.805555556	21
Thin	Dot	6 cycles	3x3 pixels	3x3 pixels	S1	BA	86.66666667	0.803333333	14
Thin	Dot	6 cycles	5x5 pixels	3x3 pixels	S1	BA	90	0.797777778	10
Thin	Linear	6 cycles	1x1 pixel	1x1 pixel	S1	BA	90	0.827777778	8

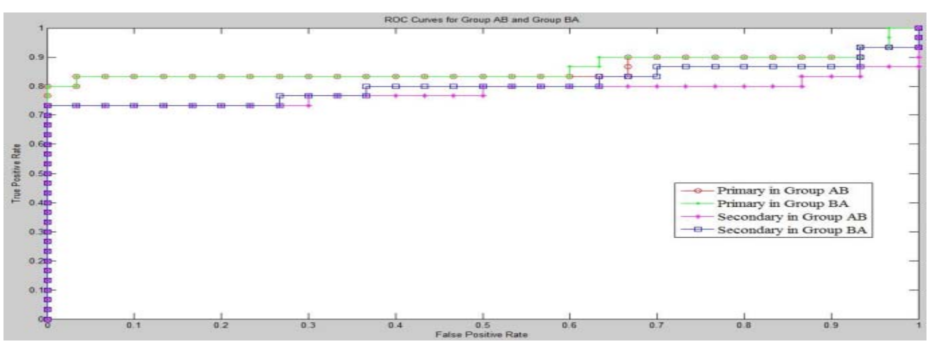

Fig.18. ROC Curve for Group AB and Group BA

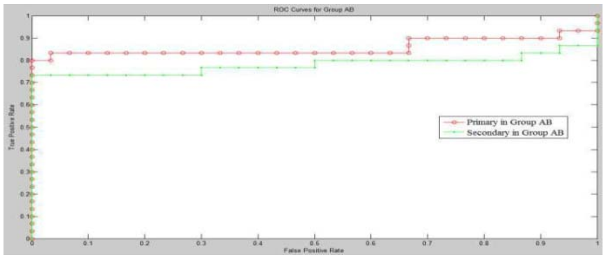

Fig. 19. ROC Curve for Group AB

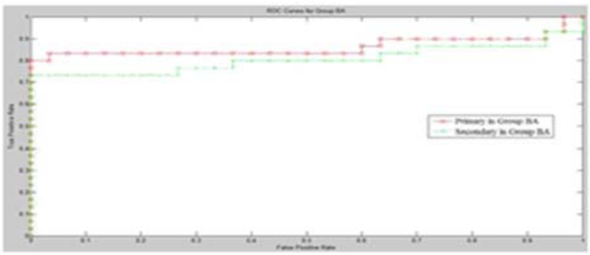

Fig. 20. ROC Curve for Group BA

5. CONCLUSION

2D PDT is a new feature extraction technique which is derived from 1D PDT to generate unique output of pulse waveform with inconstant frequency and amplitude. This technique is practically relying on the modulating signal (2D triangular waveform) to fulfill the task of feature extraction. From the experiment, it is capable to come out the best combination for the process to extract the feature of fingerprint. The result of the best combination indicates the potency and feasibility of 2D PDT to be a good feature extraction technique. As it able to gives accuracy about 87% on average and the AUC is about 0.86 on average. Therefore, it is proven that 2D PDT is a workable technique with no less favorable than other outstanding techniques.

There are some future works may further expand to improve the performance of 2D PDT. In the aspect of fingerprint, it might put in effort on the alignment technique. As fingerprint alignment is a particular topic with broad prospects for even better development. The better the fingerprint aligning may cause the precise result produced. Moreover, there is another factor might influence the result as well. This factor is related to the storage of template set of fingerprint. The template may set in the form of integration of multi-sample instead of single to resolve the little displacement after the process of alignment. Besides, 2D PDT is believed that not only applicable on fingerprint biometrics but it is also applicable on any biometrics characteristics and 2D signal. Therefore, it is recommended to further develop this technique in diversified 2D signal to increase its use value.

5. ACKNOWLEDGEMENT

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