# Second Derivative and Contour Analysis of PPG for Diabetic Patients

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***Abstract*—Diabetes mellitus is a group of metabolic diseases associated with the production and/or reaction of insulin leading to hyperglycemia. Glycated hemoglobin (HbA1c) level is generally measured for hyperglycemia. Hyperglycemia and the duration of having diabetes are two factors that contribute to developing complications. A trend of increasing arterial stiffness has been identified in Type 2 diabetes. Photoplethysmograph (PPG) pulse wave provides a 'window' into the properties of small arteries whereas stiffening of these arteries will alter the PPG waveform. In this research, the potential of PPG in discriminating type 2 diabetic patients between two different levels of HbA1c has been investigated (diabetic patient with HbA1c < 8% as controlled group and diabetic patient with HbA1c > 10% as unhealthy group). Contour analysis of PPG signal and second derivative photoplethysmograph (SDPPG) techniques have been used to identify the feasible parameter for this research. From this study, it shows that there is no significant difference for both group of diabetic patient for ratio of *b/a*, which extracted from SDPPG. The mean ratio for controlled group is 0.5692 and 0.6067 for unhealthy group, p=0.180. Other than that, the results show that there is a statistical significant different for the some variables extracted.**

***Keywords*—Diabetes mellitus; HbA1c; Photoplethysmographic pulse; SDPPG**

## I. Introduction

Detection of blood volume change in the peripheral vessels at several body locations such as toe, index finger and earlobe can be acquired using photoplesthysmograph (PPG) [1]. PPG is an optical technique implemented non-invasively which operates either at near infrared or red wavelength and frequently employed in clinical study [2]. The heart produces blood volume pulsation, which propagates through the arterial system. Pulse waves that reflected from arterial branching sites have an effect on these pulsations. Pulse waves extracted from fingertip PPG signal expresses the blood volume change at the fingertip. Information regarding vascular system characteristics, blood flow status and peripheral vessels properties can be extracted from the pulse waves. The PPG pulse waves are identical to the blood pressure pulse. This similarity can be seen on the pulse contour such as loss of pulsatility and damping for occurrences of vascular disease. The damping is related to the increased peripheral resistance and reduction in vessel compliance but no further explanation can be found about these changes.

Analysis of PPG pulse has been used for assessment of several risk including arterial stiffness and other disease [3-8]. Arterial stiffness is associated with some diseases such as diabetes mellitus [9-10], atherosclerosis [11], cardiovascular disease [12] and kidney failure [13]. Generally, one of the factors that can cause death and loss of abilities among diabetic patients is cardiovascular disease, which could be due to hypertension, high cholesterol level and high glucose level in blood and other risk factors [14-16].

Previously assessment of PPG pulse involved a healthy group as controlled group and a disease group. Appropriate variable extracted from PPG pulse for disease group is different from healthy group. Therefore, in this study, relationship between PPG pulses for two different status of diabetic patients group is investigated. In addition, several variables from PPG pulse are extracted to identify the relationship between PPG pulse and diabetic status in this study.

## II. Subject and Method

### *A. Subject*

Diabetic patients from UKM Medical Centre (Endocrine Clinic, UKMMC) voluntarily participated in this study within the duration from August 2010 to January 2011. The diabetic status of these participants was referred to clinical records for confirmation and was identified as Type 2 diabetic patient. Research and Ethics Committee of UKMMC granted approval for the study protocol and all participants agreed to give written consent. A total of 101 patients with their age within 50 to 70 years participated and these patients were divided into two groups. The groups consist of a controlled group (HbA1c level < 8%) and an unhealthy diabetic group (HbA1c level > 10%). A total of 53 patients for controlled group and 48 patients for unhealthy group took part in this study. High-performance liquid chromatography (HPLC) Ion Exchange method is used to measure HbA1c level. The measurement

Research University Grant: Q.K130000.2611.14J49.

were conducted at the pathology and hematology laboratory of UKMMC and all participants were asked to fast beforehand.

### *B. PPG Recordings*

The PPG system consists of software, hardware (OEM-601 from Dolphin Medical Inc.) and sensor to acquire PPG pulse. In order to simplify the data acquisition, data restoration and then for analysis of data, the software was pre-installed to the computer. The PPG signal is acquired using transmission PPG finger probe sensor with red light emitting diode which operated at wavelength of 660 nanometers (nm). 275 Hz sampling rate and 16-bit resolution computer system is used for data recording and the data is then saved in ASCII format. Room temperature of 25°C within clinical environment was setup for PPG signal acquisition. To ensure the acquisition of fingertip PPG signal at the heart level, diabetic patients were asked to be in a sitting position. The sensor probe was connected to index finger of the right arm within 90 seconds of recording session. Patients were asked to sit and breathe with natural and normal breathing rate during the recording session.

### *C. Data Processing*

MATLAB (The MathWorks, Inc.) is used to perform signal analysis for recorded PPG signal. Initially, two stages of preprocessing of PPG signal are involved in this study. First stage is signal detrending and second stage is band-pass filtering. Removing of outliers, motion artifacts, drifts and offset were performed with 'detrend' MATLAB function. To eliminate the effects of higher frequency disturbances and respiratory rhythm, a customized algorithm of band-pass filtering (0.6-15Hz) was used. Fig. 1 shows the PPG signal for raw signal and the two stages of preprocessing. Identification of all valleys for the PPG signal is performed using a customized PPG valley detection algorithm. Fig. 2 shows the detection of all valleys and two consecutive valleys defined as one pulse.

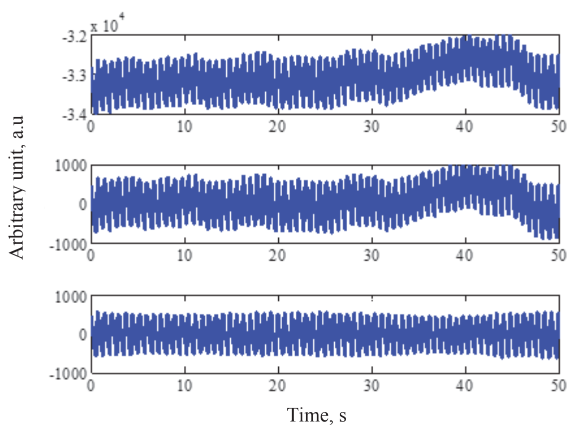


Fig. 1. (a) Raw PPG signal, (b) PPG signal after detrend and (c) Filtered PPD signal

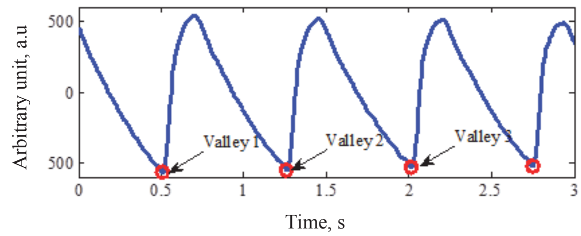


Fig 2. Identification of one pulse

Then, from the contour analysis, three parameters were extracted which are α, β and ratio of *b/a*. Trigonometric function was used to calculate α and β, in which the location of α and β are shown in Fig.3. From the second derivative of photoplethysmograph (SDPPG) technique, index of *a* and *b* were identified as shown in Fig. 4.

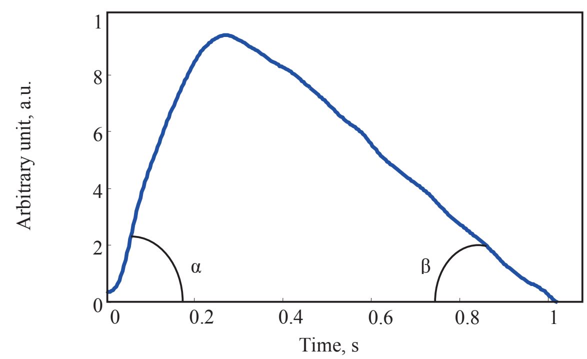


Fig. 3. Location of α and β

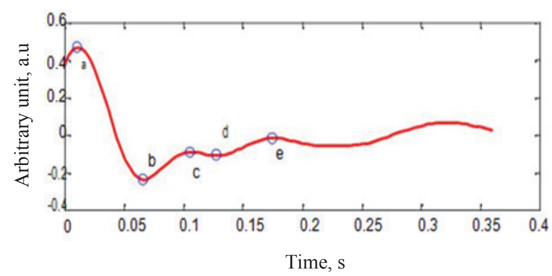


Fig. 4. SDPPG and location of index *a* and *b*

### *D. Statistical analysis*

An independent sample t-test was performed to study the equality of means for several variables between controlled diabetic patient group and unhealthy diabetic patient group. SPSS software program (SPSS 16) is used to perform statistical analysis. For this study, assumptions are made for conducting the independent sample t-test, which include (i) approximately similar group size, (ii) equal variances,

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(iii) independently observations and (iv) approximately normal distribution of dependent variable. A significant level of p-value < 0.05 is considered to be statistically significant with 95% of confidence level in comparing mean between the groups and the width of 95% confidence interval (CI). Effect size is calculated to investigate the magnitude of the difference between the two groups.

## III. Results

Statistical analysis of clinical characteristics is tabulated as in Table I. Refering to Table 1, mean of the two groups of diabetic patient is not significantly different in systolic blood pressure (systolic BP), age and high density lipoprotein (HDL). These results show that both groups have similar reading of systolic BP and HDL and similar mean of age. As compared to unhealthy diabetic patient group, controlled diabetic patient group have lower diastolic blood pressure (diastolic BP), triglycerides (TG) and low density lipoprotein (LDL). Using Chi-square, these two groups of diabetic patients have similar percentage of males, with p = 0.489. This result shows that the distribution of male and female for both groups is similar.

TABLE I. Clinical Characteristics of Studied Patients

| **Characteristics** | **Units** | **Diabetic patients with** | | | | **p-value** |
|---|---|---|---|---|---|---|
| | | **HbA1c < 8%** | | **HbA1c > 10%** | | |
| | | Mean | SD | Mean | SD | |
| Age | years | 59.28 | 4.729 | 58.17 | 5.365 | 0.269 |
| Systolic BP | mmHg | 140.60 | 17.834 | 146.73 | 20.441 | 0.111 |
| Diastolic BP | mmHg | 74.91 | 9.132 | 79.33 | 11.897 | 0.037 |
| TG | mmol/L | 1.537 | 0.861 | 2.094 | 1.151 | 0.007 |
| HDL-cholesterol | mmol/L | 1.233 | 0.330 | 1.199 | 0.353 | 0.613 |
| LDL-cholesterol | mmol/L | 2.658 | 1.040 | 3.350 | 1.449 | 0.009 |

For variables of α and β, there is a statistically significant difference between controlled diabetic patient group (HbA1c level < 8%) and unhealthy diabetic patient group (HbA1c level > 10%). Table II shows that the mean of α for controlled diabetic patient group is statistically lower than unhealthy diabetic patient group whereas the mean of β for controlled diabetic patient group is statistically lower than unhealthy diabetic patient group. Refering to Table II, it shows that there is no significant difference for both group of diabetic patient for ratio of *b/a* which extracted from SDPPG. Table III shows the listing of effect size for all variables. From Table III, it shows that the magnitude of different for mean ofα and β is moderate.

TABLE II. Analysis of Means for All Variables

| **Variables** | **Diabetic patients with** | | | | **p-value** |
|---|---|---|---|---|---|
| | **HbA1c < 8%** | | **HbA1c > 10%** | | |
| | Mean | SD | Mean | SD | |
| α | 77.5534 | 2.37185 | 78.7927 | 2.12257 | 0.007 |
| β | 58.2385 | 4.16998 | 61.0938 | 3.94411 | 0.001 |
| ratio of *b/a* | 0.5692 | 0.12442 | 0.6067 | 0.15360 | 0.180 |

TABLE III. Listing of Effect Size

| **Variables** | **t** | **df** | **p-value** | **Effect size, $\eta^2$** | **Differences in the mean** |
|---|---|---|---|---|---|
| α | -2.756 | 99 | 0.007 | 0.07 | Moderate effect |
| β | -3.526 | 99 | 0.001 | 0.11 | Moderate effect |
| ratio of *b/a* | -1.351 | 99 | 0.180 | 0.02 | Small effect |

## IV. Discussion and Conclusion

In this research, several parameters have been investigated. Referring to the results, it shows that between two different groups of diabetic patients, there is an appropriate variable that can be used to identify the group of diabetic patients based on PPG pulse wave. From this study, the results suggest that HbA1c level has significant effect on the blood volume change. The development of advanced glycation end products (AGEs) is induced by hyperglycemia among diabetic patients. Production of reactive oxygen species (ROS) in vascular endothelium is stimulated by AGEs. Thus, nitric oxide (NO) activity is directly affected by AGEs [17]. Long term of having high blood glucose level [16] together with the impact of AGE within vascular wall could enlarge artery atherosclerosis and worsen vascular stiffness [18]. Fluctuation in the blood sugar level and dehydration are contributors to the elevated of blood viscosity. Blood flow in the microvessels is influenced by both viscosity and impaired release of NO [17].

In conclusion, several parameters extracted from PPG pulse have been analyzed. From the contour analysis of PPG pulse, three parameters were extracted which are α, β and ratio of *b/a*. From the statistical analysis, it shows that there is no significant difference for controlled diabetic patient group and unhealthy diabetic patient group using parameter extracted from SDPPG technique.

## Acknowledgment

This work granted by Universiti Teknologi Malaysia (UTM) under Research University Grant: Q.K130000.2611.14J49. Authors would like to express highly gratitude to UKMMC staffs (Endocrine Clinic) for their support.

Conflict of interest: None

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