13_HASIL CEK_Blood circulation, Photoplethysmography signal, Poincaré plots, Smokers

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Poincaré plots to analyze photoplethysmography signal between non-smokers and smokers

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ABSTRACT

An analysis of blood circulation was used to identify variations of heart rate and to create an early warning system of autonomic dysfunction. The Poincaré plot analyzed blood circulation using photoplethysmography (PPG) signals between non-smokers and smokers in three different indices: SD1, SD2, and SD1 SD2 ratio (SSR). There were twenty subjects separated into non-smoker and smoker groups with sample sizes of 10, respectively. An independent sample t-test to compare the continuous variables. Whereas, the comparison between two groups employed Fisher's exact test for categorical variables. The result showed that SD1 was found to be considerably lower in the group of smokers (0.03±0.01) than that of the non-smokers (0.06±0.03). Similarly, SSR was recorded at 0.0012±0.0005 and 0.0023±0.0012 for smoking and non-smoking subjects, respectively. As a comparison, SD2 for non-smokers (25.7±0.5) was lower than smokers (27.3±0.4). In conclusion, we revealed that the parameters of Poincaré plots (SD1, SD2, and SSR) exert good performances to significantly differentiate the PPG signals of the group of non-smokers from those of smokers. We also supposed that the method promises to be a suitable method to distinguish the cardiovascular disease group. Therefore, this method can be applied as a part of early detection system of cardiovascular diseases.

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1. INTRODUCTION

Photoplethysmography (PPG) is one of the medical devices that possesses many advantages such as low-cost, high-reliability, and easy to use. The application of PPG in the public health center can help paramedics to treat patients easier. A low-priced PPG reduces healthcare service costs as well. In other that, the PPG signal is suitable to assess some of cardiovascular diseases (CVDs) such as diabetes [1]–[3], hypertension [4]–[6], erectile dysfunction [7], atherosclerosis [8], coronary artery disease [9], [10] and coronary heart disease [11]. It is also convenient for clinical application, for example, in the measurement and monitoring of heart rate [12]–[14] and blood pressure [15], [16]. CVDs as the most critical and the most significant contribution of death almost around the world recently are associated with smoking as well [17], [18]. Smoking is related to parasympathetic withdrawal and sympathetic augmentation in nerve activities [19]. Cigarette contains tobacco nicotine as a sympathomimetic agent. As a sympathomimetic agent, nicotine stimulates adrenaline secretion. Adrenaline stimulates the work of the heart and vasoconstriction of blood vessels. In addition to nicotine, cigarette also contains carcinogenic compounds that are harmful to endothelium

homeostasis of blood vessels. Disruption of endothelial homeostasis causes the impaired function of nitric oxide synthase (NOS) so that the production of nitric oxide (NO) compounds, which play an essential role in regulating blood flow, is reduced [20].

Blood regulation is associated with the peak to peak fluctuation in PPG or pulse rate variability (PRV). The PRV reveals the autonomic nervous system (ANS) time-varying [21]. The ANS is one of the components involved in regulating NO secretion. A decrease in plasma NO levels causes an increase in sympathetic nerve activity [22]. PRV derived from the PPG pulse amplitude signal is compatible with heart rate variability from electrocardiogram (ECG) and blood pressure [23]. Changes in heart rate variability (HRV) correspond to changes in PRV in both physiological and pathological conditions [24] . In healthy subjects, PRV is in line with HRV [25] both in an awake condition and a sleep state [26]. PRV contains the non-linear signal that can be analyzed by the Poincaré plot. The aim of this study is the investigation of the Poincaré plot application to analyze of blood circulation using photoplethysmography signals between non-smoking and smoking subjects. Therefore, this method can be applied as a part of early detection system of CVDs.

2. RESEARCH METHOD

2.1. The system of a low-cost PPG

The hardware system consists of Arduino Uno which has a low power and highly efficient microcontroller based on AT Mega 328 and other electronic components such as resistor, capacitor, and integrated circuit (IC), while the software consists of the Arduino integrated development environment (IDE) and LabVIEW. The hardware system also includes units such as the IR sensor, the 2nd-order high pass filter (HPF), the instrumentation amplifier (Ins-Amp), the 2nd-order low pass filter (LPF), and Arduino Uno. LabVIEW was employed to visualize and store data. The diagram of system is shown in Figure 1.

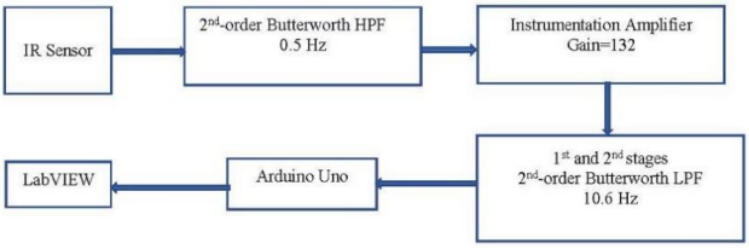

Figure 1. The diagram of a low-cost PPG system

2.2. Data acquisition

The PPG signals are recorded by using a low-cost PPG based on Arduino created by us. Furthermore, the signals were edited to get the peak to peak time (PPT). The PPT is determined by using custom software in MATLAB to analyze PRV features. Data acquisition is conducted for one minute with a sampling rate of 155 Hz. The recorded data were then digitized with 10-bit resolution and stored in a personal computer using LabView for further analysis. The signal analysis of Poincaré indices is computed by using MATLAB 2016 b (The Mathwork Inc.).

2.3. Study protocol

Twenty people, all males, are separated into two groups, namely the non-smokers and smokers, with a sample size of ten, respectively. Subjects, aged 18-35 years (average age of 25.0±4.2) were volunteers who were declared clinically healthy by doctors in primary health care. Smoker's criteria were subjects who had smoked at least one stick cigarettes/day during the past five years. On the other hand, the criteria for non-smokers are those subjects who had not smoked cigarettes in the past five years. Voluntary non-smokers and smokers are recruited from two villages in Yogyakarta, Indonesia, and from students at the Universitas Ahmad Dahlan, Yogyakarta in September 2019. Before the data acquisition, all subjects were asked to not consuming food and beverages at least for 8 hours. During the study, volunteers received health education about the dangers and adverse effects of smoking. The Health Research Ethics Committee of the Faculty of Medicine and Health Sciences, University of Muhammadiyah Yogyakarta had responsibility to approve this study (number:166/EP-FKIK_UMY/V/2019).

2.4. Poincaré plot analysis

PRV derived from PPG pulse amplitude signal can be analyzed by Poincaré method. The conservative 2D Poincaré plot; i.e., the first delayed Poincaré plot, can be produced by plotting each PPT of PPG as a function of its previous PPT ([PPT(n), PPT(n+1]). The time from the fixed sequence of PPT in (1) is selected, and then the set of the first delay on the time of PPT (2) is defined as follows:

$$PPT' = \{PPT(1), PPT(2), \dots, PPT(n-1)\} \quad (1)$$

$$PPT'' = \{PPT(2), PPT(3), \dots, PPT(n)\} \quad (2)$$

There are three indices of the results: the standard deviation (SD) of the short term of PPT or SD1 in (3), the SD of the long term of PPT or SD2 in (4), and SSR in (5).

$$SD1 = \sqrt{\text{var}(PPT' - PPT'')/\sqrt{2}} \quad (3)$$

$$SD2 = \sqrt{\text{var}(PPT' + PPT'')/\sqrt{2}} \quad (4)$$

$$SSR = SD1 \ / \ SD2 \quad (5)$$

2.5. Statistical analysis

The distribution of the data was normal. The data expressed as mean ± standard deviation (SD). The statistical analysis applied SPSS ver. 22 to determine whether there are differences between the groups of non-smokers and smokers when more than one PRV feature is obtained. We used independent sample t-test to contrast the continuous variables. Whereas, comparison between two groups employed fisher's exact test for categorical variables. P<0.05 is considered statistically significant. The PRV features (SD1, SD2, and SSR) are the dependent variables.

3. RESULTS AND DISCUSSION

3.1. Features of non-smoking and smoking subjects

Table 1 shows the characteristics of subjects either non-smoking or smoking subjects. All subjects are male to show there is no gender difference in this study. The non-smoking and smoking subjects also similar in their age (24.0±2.8 and 25.9±5.2). The non-smokers showed remarkably lower blood glucose levels than those in the smoker subjects ($p<0.05$). On the contrary, others demographic parameters (height, weight, body mass index (BMI)) and hemodynamic parameters (systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate) were similar between the two groups.

Table 1. Features of non-smoking and smoking subjects

Parameters	Non-smoker n = 10	Smoker n = 10	p-value
Male, %	100	100	1.000
Age, year	24.0±2.8	25.9±5.2	0.327
Height, m	1.70±0.04	1.68±0.06	0.437
Weight, kg	67.9.±19.5	65.5±11.7	0.741
BMI, kg/m^2	23.5±6.9	23.0±4.3	0.866
SBP, mmHg	118.8±12.5	128.5±11.5	0.088
DBP, mmHg	84.4±9.1	82.0±9.2	0.565
Heart Rate, mmHg	84.3±9.1	79.8±10.5	0.484
Blood Glucose, mg/dL	83.8±31.6	166.1±99.9	0.040

3.2. Comparison of Poincaré plots between non-smoker and smoker

The comparison of raw PPG signal and Poincaré plot displays in Figure 2. The Figure 2(a) is a raw PPG signal of a non-smoker, while the Figure 2(b) is Poincaré plot of PPG signal from a non-smoker. Otherwise, Figure 2(c) shows a raw PPG signal of a smoker and Figure 2(d) presents Poincaré plot of PPG signal from a smoker. The PPG signal amplitude of non-smoker is higher than smoker (left side). It confirms that the blood circulation of non-smoker is more smoothly than smoker. The distinction of non-smoker and smoker also can be seen from the Poincaré plot section (right side). It shown that the short-term variation of

PPG signal of non-smoker is wider than smoker relating to blood moving in the arteries. On the other hand, the long-term variation of PPG signal of non-smoker is slighter than smoker.

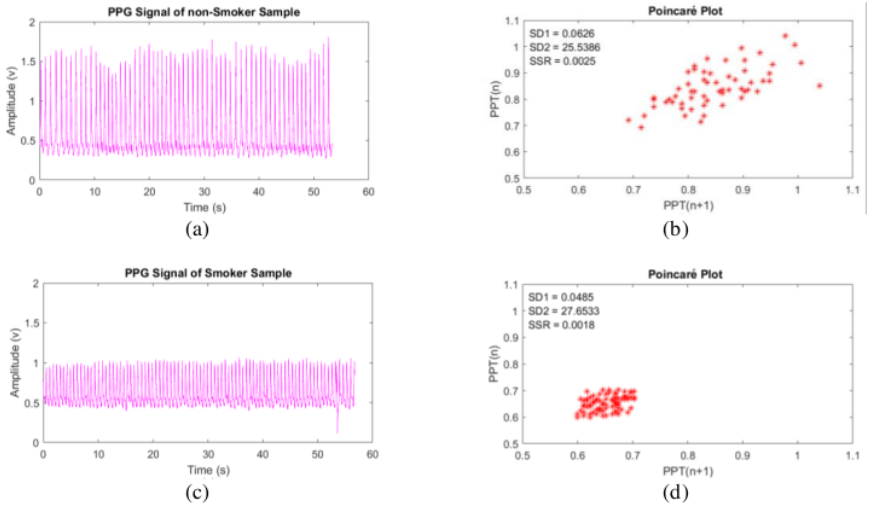

Figure 2. Raw PPG signal of (a) a non-smoker, (b) Poincaré plot of PPG signal from a non-smoker, (c) smoker, and (d) Poincaré plot of PPG signal from a smoker.

3.3. Correlation of SD1, SD2, and SSR between non-smokers and smokers

The two essential parameters of Poincaré method are SD1 (relates to short term variations of PRV) and SD2 (corresponds to long term variations of PRV). SD1 was significantly lower in smoker participants than that in their non-smoker counterpart as shown in Table 2. This results are more accurate than another similar work [19]. The difference between two groups might be related to nicotine in cigarette. Nicotine stimulates adrenaline secretion, while adrenalin stimulates the work of the heart and vasoconstriction of blood vessels. Smoker has more nicotine than non-smoker, therefore it could be influence in the blood circulation. On the other hand, the SD2 of non-smokers is lower than smokers due to correspond to the reduction of arterial function. Smoking is one of the prospective causes in buildup of fatty substances in the blood vessel. Plaque in the walls of the blood vessel might resist the blood flow through the arteries. As a result, supply blood to the heart become decline of oxygen-rich blood to the heart, especially during the time of increased activity. A heart dysfunction or injury to the heart muscle will be occurred when the coronary arteries are completely blocked.

Table 2. Relationship of SD1, SD2, and SSR between non-smokers and smokers

Parameters	Groups (mean±SD)		p-value
	Non-smokers	smokers	
SD1	0.06±0.03*	0.03±0.01	0.024
SD2	25.7±0.5**	27.33±0.36	0.000
SSR	0.0023±0.0012*	0.0012±0.0005	0.015

4. CONCLUSION

The three parameters of Poincaré plots exert good performances to significantly differentiate the PPG signals of the non-smoker's group from those of smokers. We revealed that the parameters of Poincaré plots including SD1, SD2, and SSR exert good performances to significantly differentiate the PPG signals of the group of non-smokers from those of smokers. We also suppose that the method promises to be a suitable method to distinguish the cardiovascular disease group, especially to detect the blood circulation status between non-smoking and smoking subjects. Therefore, this method can be applied as a part of early detection system of CVDs.

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