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A Correlation Study on Motion Artifact using Photodiode and Three Axis Accelerometer Signals

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Abstract

Objectives: The three-axis accelerometer used to reflect the Motion Artifact (MA) implemented in the Adaptive Noise Cancellation (ANC) technique has failed to provide the required MA for accurate processing. This study investigates the validity of using a Covered Photodetector (CPD) for MA detection to unify the sources of generated desired and MA signals to avoid electronic noise differences. **Methods/Statistical Analysis:**The two devices were fastened together and exposed to various kinds of motions. The Amplitude Fluctuations (AFs) responding in the time domain and the Linear Correlation Coefficient (r) were observed. **Findings:**Confirmed the proposed approach validity by pointing a rapprochement in AFs. The calculated r was0.999 in asteady state while in motion states rangesfrom 0.998 to 0.794 according to movement changes. **Application/Improvements:** Implementing such concept for Photoplethysmography signal processing within ANC leads to a curate critical medical diagnosis at a lower cost.

Keywords: Covered Photodetector, Motion Artifact Reflector, PPG Signal, Three-Axis Acelerometer

1. Introduction

The Photoplethysmographic sensor is an optoelectronic device used to non-invasively measure the continuous change of blood flow in arterial vessels. It uses a LED light source and photodetector assembled intoclip probe to monitor the cardiovascular pulse waves that propagate through the blood vessels.Photoplethysmographic (PPG) signals are used to determine the Heart Rate HR, oxygen saturation, Respiratory Rate(RR) and fetal heart rate[1,2]. They are obscured during movements as a side effect of induced noise by motion, causing an inaccurate reading and interpretation of the PPG signal[3,4].

The ANC is one of the several techniques emerged to provide the valid PPG signal in anon-stationary state thatit depends on adaptive filtering.The originally induced noise reference is required for updating the filter coefficients continuously[5]. Two main approaches have been utilized to provide the reference MA,usingextra hardwares such as 3-axis accelerometer[6,7] and synthetic noise signal extracted from the contaminated PPG signal itself[8,9]. However, the acquired reference signal from those approaches has failed to match thereal reflectionfor entire induced noise due to the motion action. The drawback of first method is, theaccelerometer does not reflect thehigh correlation between motion artifact and the acceleration data[10]. For the second method,it is noteasytoproduceexact estimate computation under the frequency interference of the desired and occurred noise signals especially during fast movements also, it iscomputationally exntensive[11,12].

In study[13], two photodetectors and one LED were utilized whereas in study[14], two LEDs with different wavelengths of Red and Green lights and one photodetector were used. Both studies adopted the differential measure-

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ments between the resulting two signals to remove the noise. The reported results were limited to some kind of movements in both works due to difficulties in providing equal amplitudes for two signals during sudden changes of motion as a precondition for effective differential measurements. Therefore, the need for new approach still exists to save the PPG sensor's potential.

In this work, we investigate a new concept to reflect the real induced noise based on generated photocurrent in dark state by the CPD, in order to avoid the differencesin electronic noise occurringwhen a different type of devicesare used for obtaining theimportant signals. An accelerometeris a classic choice to provide the reference MA that actually reflects the change in piezoresistance during motion[8]. Whereas, the PPG signalis a result of counting the photoresistance change[15]. Both devices are subjected to the motion and electromagnetic environmental effects due to their nature as electronic equipment, thus causing different types of electronic noise[16,17] that lead to new negative impacts. Hence, the only way to provide identical MA is to make the desired and resulted noise signals generated from similar twin sources. To validate this concept, several experiments have been conducted on both tied sensors. Thethree-axis accelerometer and the covered photodetector were undergone to different kinds of motions in the aim to analyze their response under same conditions. Data were collected for six consecutive seconds in silence and motion states along with X, Y, Z, rotating, rolling, walking, and jogging. The results were analyzed through linear correlations criteria which indicated highly positive in sharing close response in reflecting various motions in addition to total correspondence in silence state.

2. Materials and Methods

2.1 Experimental Setup

A custom hardware and software have been designed and developed using Lab VIEW 2015 and DAQ-NI 9215 (National Instruments Corporation). Data were acquired simultaneously from 3-axes accelerometer (AD335, Analog Devices) and traditional PPG sensor type (Nellcor DS-100A) with covered photo-sense area by an optical baffle to prevent the light effect. The generated dark photocurrent is exploited to represent the induced noise that identically generated within corrupted PPG signal at the same time. The signals were digitized using four channels DAQ-NI 9215 as shown in Figure 1.

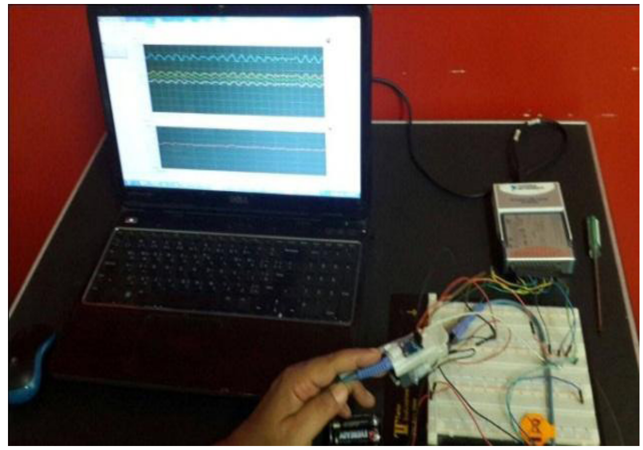

Figure 1. Experimental Setup.

Data was sampled at 100 Hz and 100 samples per channel in six consecutive seconds. In two states of silence without the effect of a fan or air condition just kept on the table trying to achieve the maximum stability. Also seven activities by moving the tied devices along with X, Y, Z axis as well as of rotating, rolling, walking, and jogging. The work has got the Ethical Approval of (IREC 619).

During the computation process for the linear correlation coefficient, the three channel outputs of the accelerometer have been combined using equation (1).

$$Z_x = \sqrt{x^2 + y^2 + z^2} \quad (1)$$

Where Zx is the combined signal of the 3-axis accelerometer channels X, Y, and Zsignals. Whereas, Zy will represent the resulted signal of the CPD.

2.2 Correlation Study

The goal of a linear correlation analysis is to identify and measure the strength of the relationship between two variables. It is also known as Pearson's correlation coefficient. In all our applications, the combined signal of 3-axis accelerometer will be represented by x whereas the signal of the CPD will be denoted by Y. The equation (2) is used to calculate the linear correlation.

$$r = \frac{\Sigma Z_x Z_y}{n} \quad (2)$$

where Z_x and Z_y are the standardized Z-values of **X** and **Y**. The standardized Z-values indicate how many standard deviations **X** and **Y** are above or below the mean.

Moreover, σ and σ^2 are standard deviation and variances respectively and can be determined as in equation (3):

$$\sigma 2 = \sum_{i=0}^{n-1} \frac{(x_i - \mu)^2}{w} \quad (3)$$

where n is the number x elements and μ is the mean of x, which could be calculated as in equation (4).

$$\mu = \sum_{i=0}^{n-1} \frac{x_i}{n} \quad (4)$$

where *w*is equal to n if weighting is set to population and equal to (n-1) when weighting is configured to sample. The correlation coefficient, r, is always ranging between -1to 1. When it is one, it means that the two variables are in maximum positive correlation and their data points forms a positive slope line. While the variables x and y are in maximum negative. When r is equal to -1, then the data points gather in the negative slope line. In the case where r = 0, it indicates that there is no correlation between both variable, x and y[18].

3. Results and Discussion

In this section, we discuss the compatibility between the resulting signals of the CPD and accelerometer.

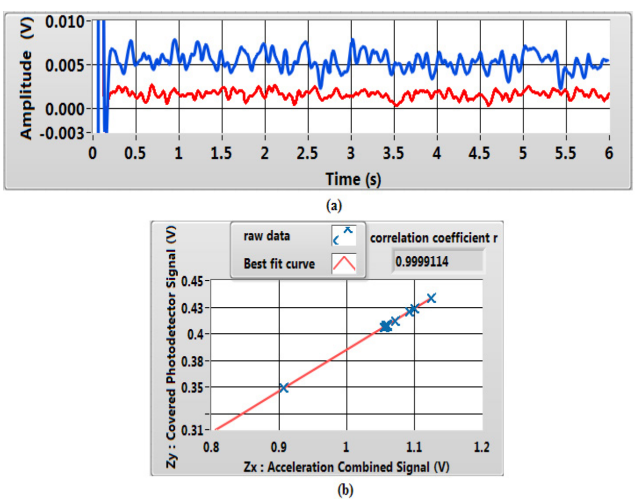

Figure 2. During steady state for continuous six seconds, a) The amplitude fluctuate between the signals of acceleration in Blue and the CPD in Red, (b) Is the linear correlation of acceleration on the X axis and CPD on the Y axis.

3.1 Silence State

this state where there is entirely no motion effect the amplitude fluctuations for the two output signals are highly convergent, as seen in Figure 2 (a). The linear correlation coefficient (r) is 0.9999, which means the two devices are quite corresponding with each other in reflecting this condition of the steady state as indicated in Figure 2 (b).

3.2 Motion State

In the motion state, amplitude fluctuations for both signals reported lower matching as compared to the matching level in silence state between the two approaches response against the motion, represented by acceleration signal in Blue and CPD in Red as shown in figure 3 (a). The total computed coefficients of linear correlations for the seven activities decreased and ranged from 0.79494 when moving along Y axis to 0.99838 when walking activity was carried out as shown in figure 3(b) and (c), respectively.

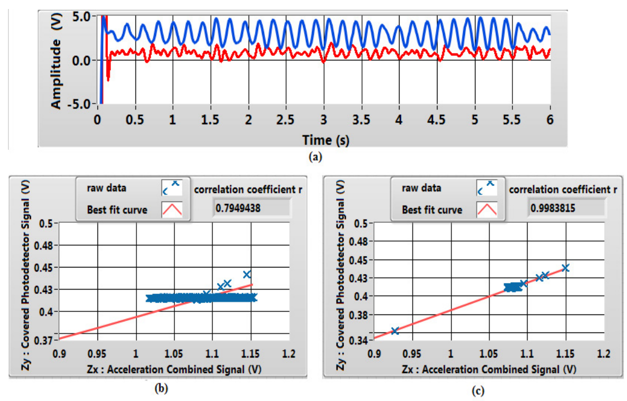

Figure 3. (a) The amplitude fluctuates in motion along the Y axis, (b) and (c) are the maximum and minimum correlation coefficients, between the acceleration and CPD signals, during moving along Y respectively.

Since the two devices are capable of pointing the effect of motion in a convenient extent. More precisely the CPD as a photodetector is designed to convert the light power into electrical energy while the accelerometer is customized to convert the Gravity effect on peso-resistance into electronic signal; they share same ability in sensing and reflecting the motion effect[19]. But the critical question is, do the two sensors sense and reflect the same total induced noise (motion artifact) caused by motion in one similar value? The right answer to this inquiry is confirmed by the noticed differences of the resulted linear correlations that the two concepts arenot completely matched in indicating the real generated noise.

The minor difference in amplitude trends and linear correlations coefficient as seen in figure 3(a) and (b) due to electronic noise emergence as a result of different hardware component designs complying with each sensor's function[20]. Hence, the accelerometer cannot indicate the same noise magnitude that has corrupted the PPG signal which is already generated by a photo detector as would be further explained.

What is notable in Figure 4 is the gradient degradation for the correlation coefficients between the three most significant movements along the X, Z, and Y axis according to their position with the level of the earth surface. The logic interpreter for such case is the accelerometer customized to respond to the phenomena of gravity while the photo detector is a transducer response to light intensity change. The effects of electronic noise in each electronic system is caused by; any degree of free motion, statistical fluctuations of generated current and thermal noise of resistances along with the environmental electromagnetic field[17,18].

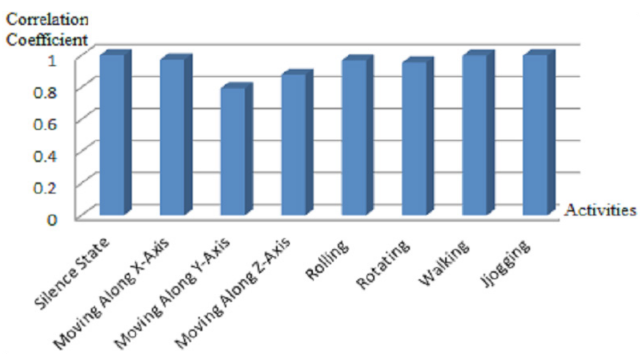

Figure 4. The Various Linear Correlations Coefficients for Reflecting Different Activities within Entire Six Seconds.

The small difference in resulting correlations is very meaningful in the collected measurements of such sensitive and critical PPG signal associated with cardiology diagnosis. Since the covered photo detector is capable of indicating the motions effect through the existed dark photocurrent, it is well qualified to be the best reflector for quite separate MA. The variances occurred in measured r confirm the need for recruiting similar sources to generate the desired and MA signals to meet the most important pre-condition of obtaining the real reference noise for reliable implementation of ANC technique.

4. Conclusion

From the aforementioned outcomes, we can conclude that both concepts have an evenly-matched reaction in various states, in the steady state is closest to the absolutely correspondent of 0.99991 in. In motion state, the linear correlations r ranged from 0.79494 to 0.99838 due to the different electronic noise emergence, usually is not taken into consideration during processing such sensitive and informatics signal. These results reinforced the possibility of using covered photo detector as a reliable MA reflector to provide a real reference signal based on generated dark photocurrent in the CPD for precise implementation of ANC in order to process the contaminated PPG signal instead of using the accelerometer. Adopting the new concept opens a new horizon for more specific applications in term of features extraction for various diseases diagnosis with less computational complexities. Practical application of this approach will be presented in our future works.

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