The Correlation of Blood Glucose Concentration and the Movement of Laser Secondary Speckle Pattern of the Artery

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Abstract. Blood glucose is the molecule needed for human life, it usually measured invasively (by taking blood). But that measurement is still very vulnerable. The alternative method namely the non-invasive method is very interesting. In addition, the article [1] explains the relationship between the movement of the arterial pulse with glucose concentration, therefore the research study to investigate the correlation between the blood glucose and the movement of laser speckle pattern resulted from the arterial movement will be promising as the non-invasive method for measuring the blood glucose concentration. In this study, the laser speckle pattern imaging method, where the microscopically movement of the object is illuminated by a laser beam and recorded by the high-speed camera in a certain interval time, are used to identify the movement patterns of the artery. From the image processing, the graphs such as electrocardiograph (ECG) can be extracted. The average of the maximum peaks of the graph can be correlated with the blood glucose concentration in the blood, as the same as shown in the article [2]. From the data that has been obtained in this research, the movement of the speckle tends to increase in accordance with the rise of blood glucose concentration.

1. Introduction

Blood glucose or glucose (C6H12O6) in blood is a molecule that’s very important which provides energy to all cells in the body. If the number of glucose not stable, it can cause health problems. Therefore, blood glucose checking is really needed. Blood glucose checking can be done by invasive and non-invasive way. Invasive way means that the blood glucose will be checked by taking blood sample of the patient to be analyzed in the laboratory or by using glucometer.

The other way is the one that has been developed by researchers [1] [2] which is non-invasive method where the blood sample is not taken to check the blood glucose.

In this research, the experiment such as the previous research which is explained in the interconnected articles [3], [4], [5] has been conducted. Those articles study about the microscopically movement of reflection from laser beam which illuminate the skin near artery. From the movement, it can be correlated with the arterial movement which later can be correlated to many things but more specifically to blood glucose concentration and dehydration. On article [3], researchers try to develop a new method to see the movement of arterial pulse that can estimate blood pressure from movement of speckle which can be read from around the pulse. Later on, speckle pattern reading method is developed more and more on the article [4] for other things, which are to be correlated with changes of blood glucose. This article doesn’t show how the data can be processed to be certain kind of data such as ECG.
In this research, more detail methods in the data processing have been done so data like ECG can be obtained and later on will be correlated with blood glucose. In the other side, the camera that will be used is pocket camera with lower frame rate than the frame rate from the previous experiment.

2. Theoretical explanation

Blood flows through all part of the body transmits substance and oxygen that are needed by body tissues. One of the transmitted substances is blood glucose. The amount of blood glucose will influence the blood parameter like how L. S. Jefferson explained on reference [4].

\[
C_v(t) = \frac{(1 - \varepsilon) \cdot q_0 \cdot h(t)}{F}
\]  

(1)

Where \(C_v(t)\) is the concentration of glucose on venous at certain \(t\) time, and \(F\) is blood flow which is represented as glucose content. The glucose pulse is symbolized by \(q_0\), where that symbol represents the amount of glucose in milligram (mg) in kilograms of blood per one heartbeat. \(\varepsilon\) is part of the glucose pulse that is extracted by blood system and metabolism that will not pass the vein. \(h(t)\) is a factor from organ that causes delay and distortion on the glucose pulse at the vein.

Based on article [6], if \(h(t) = 1\), and total of all \(q_0\) is \(C_{\text{artery}}\), F and total of all \(C_v(t)\) is \(C_{\text{vena}}\), where \(C_{\text{artery}}\) and \(C_{\text{vena}}\) is concentration of glucose on artery and vena. From that, \(\varepsilon\) can be written like the equation below:

\[
\varepsilon = \frac{(C_{\text{Arteri}} - C_{\text{Vena}})}{C_{\text{Arteri}}}
\]

(2)

Concentration of glucose on artery and vena is proportional with glucose pulse \((q_0)\) and blood flow \((F)\).

Based on article [3], the relation between the radial movement of blood vessels \((dr)\) with pressure change on vessel is shown by the equation below:

\[
dr \approx \frac{r}{E} dP
\]

(3)

Where \(r\) is the value of radius of vessel and \(E\) is elastic modulus of vessel wall. So the radial relative changes are linear to the pressure of vessel. This research uses laser as the medium to see the small changes.

When laser is illuminated to rough area, granularity pattern will be formed. These patterns will be formed when laser which is coherent touches the area of rough surface so the reflection will disperse to all directions and will result laser speckle patterns.

The speckle in this research is obtained subjectively because the obtained speckle structure is based on parameter of reading system like if the size of lens aperture is bigger, the size of speckle will change, and if the imaging position is changed, the obtained pattern will also change to be unsuitable for the initial pattern.

The size of area can be determined by diffraction-limited resolution from Airy disk lens which diameter can be obtained by formula (4) like the equation below [5]:

\[
d = \frac{2.4\lambda u}{D}
\]

(4)

Where \(\lambda\) is wavelength from laser beam, \(u\) is the distance from object to lens and \(D\) is diameter of aperture.

A. Ullal [7] have investigated about how to process the movement of laser speckle. When the object does tilting process with \(\alpha\) as the angle like in Figure 1, sensor will read the laser speckle pattern which also moves or shifts.
Based on article from Z Zalevsky [4], it is explained that the tilting movement has correlation with shifting movement from camera reading so the equation below can be adaptable.

$$\beta = \frac{4\pi \tan \alpha}{\lambda} \approx \frac{4\pi \alpha}{\lambda}$$  \hspace{1cm} (5)

From the equation (5), $\beta$ is relative shifting from laser speckle pattern to object changes, $\alpha$ is a tilting angle from an object and $\lambda$ is wavelength from the laser.

$$\tan \alpha \approx \alpha \approx d$$  \hspace{1cm} (6)

where $d$ is the changes that happen on the vibrating object. Based on [4], the change of glucose flow is proportional to shift changes on laser speckle pattern

$$C_v(t) \propto \beta(t)$$  \hspace{1cm} (7)

3. Experimental results
The system that’s used in this research can be seen on Figure 1. From this figure, it can be seen that there’s a green laser (532 nm) which is directed to the part of artery. Gypsum is applied around the wrist to prevent any movement, but a hole with the size of laser beam is made on part of the pulsating artery. After that, camera will be positioned to the side with an angle of 45 degree from the direction of the illuminated beam. Other than that, there’s 10 centimeters distance from the lens to the reflection and this is based on Airy disk pattern which can be obtained from Airy disk formula (4) above by determining the aperture of the used lens, laser and the distance from the beam source. Camera that’s used has size of 512x384 pixel with frame rate of 240 fps and have focus lens 4.5-45.0 mm with aperture lens opening 1:3.5 - 6.5. Recording process and data taking can be seen on Figure 2.

There are some steps which are needed to be followed like on Figure 3, to change the laser speckle pattern so pulse like ECG can be obtained. The result of recording is in form of video recording with duration of 10 seconds which has 512x384 pixel and frame rate of 240 fps which can be seen on Figure 2.

After the image is taken, then the preprocessing and image segmentation will be conducted. The purpose of this is to make processing becomes easier to obtain pulse like ECG. For the process itself, there are several steps, which are, for the first, image will be rotated with the same direction of laser speckle movement, after that from the rotation, vertical movement of the speckle will be obtained. Then, it will be separated from its background. Object separation on this phase is conducted to get an image that will be able to be cut and it also helps the processing becomes easier, then the value of the green one will be taken because the green one is more dominant. These process will be done for every frame.
Figure 4. before (left) and after (right) rotation

Figure 5. The result of image cropping

Red Green Blue

Figure 6. The result of RGB separation

Figure 7. The result of processing like ECG

After being processed in the previous step, the next process is image correlation processing [6] that will be conducted to determine the movement of speckle. The first thing that’s needed to do in this image processing is taking a small part of speckle pattern on initial frame, 81x81 pixel of every small pattern in the middle of the picture that has the initial coordinate.

The next step is searching for the highest correlation value between patterns in previous 81x81 pixel square and the picture in the next frame. Every pixel on the frame which is tested with 81x81 pixel square will be analyzed based on its highest correlation. The coordinate of the area that has the highest correlation will be used as the new coordinate origin and this is called movement of laser speckle. Based on article [8] below, the best method to determine the correlation on laser speckle pattern is C3 method.

\[
C3 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} [f(x_i, y_j) - \bar{f}] [g(x_i, y_j) - \bar{g}]^2}{\sum_{i=1}^{n} \sum_{j=1}^{m} (f(x_i, y_j) - \bar{f})^2 \cdot \sum_{i=1}^{n} \sum_{j=1}^{m} (g(x_i, y_j) - \bar{g})^2}.
\]

\(\bar{f}\) is the average intensity of laser speckle pattern on the first frame, \(f(x_i, y_j)\) is intensity of every pixel with coordinate \((x_i, y_j)\), \(\bar{g}\) is the average intensity of laser speckle pattern on the second frame (after movement), and \(g(x_i, y_j)\) is intensity of every pixel with coordinate \((x_i, y_j)\).

After obtaining the highest correlation, the changes are called movement of laser speckle. Then, every frame from the pictures is processed and the obtained result from the experiment is shown on Figure 7.

A series of tests need to be carried-out to test whether the obtained data has correlation with blood glucose. Data from every test is compared with a measurement instrument (glucometer) which has high accuracy based on article [7]. There are 2 types of tests, which are stability test and dynamic test.

Stability test is a test to see whether the used instrument has measurement value be relatively the same as when there’s no changes in parameter. This test is done to one healthy non diabetic person with duration of 30 minutes and time interval of 5 minutes. The result can be seen on Figure 8(a).

Dynamic test is a test to see changes that happen when there are parameter changes in subject which in this matter is the blood glucose concentration. This test is done to 5 healthy non diabetic people with duration of one hour and time interval of 10 minutes. But before doing this, these 5 peoples will have to drink a high glucose drink.
In the stability test data, the data that have been compared are the blood glucose concentrations which have the mostly constant values with average values of the maximum peaks from the movement of laser speckles. This shows that the developed instrument is stable when there are no changes in parameter.

In the dynamic test data as on Figure 9-12. have a mostly good level of correlation between the average amplitudes of the like ECG graph resulted from the camera and blood glucose concentration with correlation value of about 80%. But the Figure 13. subject has low level of correlation with value of 63%. This is caused by the significant movement of the subjects’ arms.

4. Conclusions
From the experiment that had been done, it can be seen that the movement of laser speckle pattern has high correlation to changes of blood glucose concentration and the used instrument is stable which is showed by the barely changed result of the stability test. In the future measurement blood glucose using low budget camera is possible. By using different way to take data and the use of a pocket camera, it can also be generated changes in the peak of laser speckle pattern.
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