Optically Remote Noncontact Heart Rates Sensing Technique

W Thongkongoum*, S Boonduang and P Limsuwan
Department of Physics, Faculty of Science, King Mongkut’s University of Technology Thonburi, Bangkok 10140, Thailand

*E-mail: sm_eternal@hotmail.com

Abstract. Heart rate monitoring via optically remote noncontact technique was reported in this research. A green laser (5 mW, 532±10 nm) was projected onto the left carotid artery. The reflected laser light on the screen carried the deviation of the interference patterns. The interference patterns were recorded by the digital camera. The recorded videos of the interference patterns were frame by frame analysed by 2 standard digital image processing (DIP) techniques, block matching (BM) and optical flow (OF) techniques. The region of interest (ROI) pixels within the interference patterns were analysed for periodic changes of the interference patterns due to the heart pumping action. Both results of BM and OF techniques were compared with the reference medical heart rate monitoring device by which a contact measurement using pulse transit technique. The results obtained from BM technique was 74.67 bpm (beats per minute) and OF technique was 75.95 bpm. Those results when compared with the reference value of 75.4±1 bpm, the errors were found to be 1.01% and 0.69%, respectively.

1. Introduction
The 3 electrodes ECG (electrocardiography) technique is the common method for measuring the sportsman heart rates activity. The drawback is the limited movement of the sportsman due to the sensors and cables. In this research, the optically remote sensing technique was proposed. To eliminate the cables and contacts of the sensors, the green laser was projected onto the skin at the carotid artery of the sportsman. The periodically changes of the interference patterns of the reflected light were analysed for the heart rate values.

2. Literature review
2.1. Heart rate
Heart rate pulse is generated from the compression and expansion of the heart which can be measured in any place that the artery align such as, on the neck (carotid artery), on the inner of both elbows (brachial artery), on the lateral of the wrist (radial artery), on the medial of the wrist (ulnar artery), at the groin (femoral artery), behind the knee (popliteal artery), near the ankle joint (posterior tibial artery) and near the both anklebones (dorsalis pedis artery) [1]. This research work was focused on the optically remote sensing technique for measuring the heart rates at the left carotid artery.
2.2. Motion tracking
Motion tracking is a process to find the motion vectors that perform the transformation of objects data from the initial frame to the next frame. Two basic methods used to determine the motion vectors are block matching (BM) and optical flow (OF) techniques.

2.2.1. Block matching. The JPEG file structures consisted of 3 colours intensity (YCbCr) of each pixel and the reference position (0, 0) at the left top of the picture. The group of ROI pixels (YCbCr, x, y) in the initial frame are computed and set as the reference values. The nearest statistical values mean absolute deviation (MAD) or mean squared error (MSE) [2] of the ROI in the next frame was estimated as the change in position of the ROI from the initial frame.

2.2.2. Optical flow. The pixel-based motion estimations were used to determine the motion vectors of all pixels in the picture. One of these methods is optical flow technique [3]. The optical flow technique is based on the assumptions given below.

1) Brightness constancy assumption:
The initial assumption is referred to the gradient-based estimation that assumes all pixel intensities which translate from the initial frame to the next frame are constant.

\[ I(\vec{s}(t), t) = I(\vec{s}(t) + \vec{u}, t+1) \] (1)

Where \( I(\vec{s}(t), t) \) is the pixel intensities as function of position \( \vec{s}(t) = (\vec{x}, \vec{y}) \) and time \( t \), \( \vec{u} = (\vec{u}_x, \vec{u}_y) \) is the pixel two dimensions velocity.

Approximate the right hand side of Eq. (1) by using a first-order Taylor series.

\[ I(\vec{s}(t)+\vec{u}, t+1) \approx I(\vec{s}(t), t) + \vec{u} \cdot \nabla I(\vec{s}(t), t) + I_t(\vec{s}(t), t) \] (2)

Where \( \nabla I = (I_x, I_y) \) denote the spatial partial derivatives of the pixel intensities, \( I_t \) denote the temporal partial derivatives of the pixel intensities.

Ignoring higher-order terms in the Taylor series and then substituting the linear approximation into Eq. (1) yields the gradient constancy equation, Eq. (3) [4].

\[ \nabla I(\vec{s}(t), t) \cdot \vec{u} + I_t(\vec{s}(t), t) = 0 \] (3)

2) Gradient constancy assumption:
From the brightness constancy assumption, the translation pixel intensities are constant. The temporal derivative of intensities is zero. Expanding the temporal derivative of intensities using the chain rule gives Eq. (4).

\[ \frac{d}{dt} I(\vec{s}(t), t) = \frac{\partial I}{\partial \vec{x}} \frac{d\vec{x}}{dt} + \frac{\partial I}{\partial \vec{y}} \frac{d\vec{y}}{dt} + \frac{\partial I}{\partial t} \frac{dt}{dt} = \nabla I(\vec{s}(t), t) \cdot \vec{u} + I_t(\vec{s}(t), t) \] (4)

Where \((\vec{u}_x, \vec{u}_y) = (\frac{d\vec{x}}{dt}, \frac{d\vec{y}}{dt})\) denotes the optical flow.

3. Experimental methods
The experimental equipment was setup to evaluate the possibility of this research technique as shown in Figure 1. The green laser (5 mW, 532±10 nm) was projected on the front mirror (in the vertical plane xy) of which attached to the loudspeaker. The loudspeaker driven by 2.50 Hz sine wave oscillator forced the mirror to move in the direction of ±z axis. The movement of the reflected green laser on the screen was recorded by a digital camera (Canon EOS 1100D). The recorded videos were manually analysed and compared to the reference frequency value 2.50±0.5 Hz (150±30 bpm) of the oscillator. The green laser was then projected onto the skin at the carotid artery on the neck. The reflected interference patterns on the screen were recorded by the same digital camera. The recorded videos were analysed by means of BM and OF techniques to find the motion vectors of the ROI in the
reflected interference patterns. The heart rates were then extracted from these motion vectors and compared to the reference value (75.43±1 bpm) [5] from the medical heart rate monitoring device (Polar FT7).

Figure 1. Experimental setup (a) assumption test (b) human heart rates acquisition test.

4. Results and discussion

4.1. Assumption test results

The results of the recorded videos of the periodically changes of the reflected light are shown in Figure 2.

Figure 2. The periodically changes of the reflected light on the screen at (a)-(f) 0.04 s, 0.16 s, 0.20 s, 0.28 s, 0.56 s and 0.40 s, respectively.

The numerically analysis of the ROI positions in the reflected light are shown in Figure 3. The periodically changes of the reflected light were 17 periods in 7.00 seconds (σ=0.47, coefficient of variation (CV)=7.20). This value corresponded to the heart rate of 2.43 Hz (145.8 bpm). This result was compared with the reference oscillator value of 2.50±0.5 Hz (150±30 bpm). The error was found to be 2.80%.

Figure 3. Variation of ROI positions on the y-axis as a function of time.
4.2. Human heart rates acquisition results

The results of the recorded videos of the interference patterns on the screen are shown in Figure 4. The periodically changes of the ROI positions were analysed by BM and OF techniques (as shown in Figure 5). The heart rates obtained from BM technique was $74.67 \text{ bpm} (\sigma=1.83, \text{CV}=17.79)$ and OF technique was $75.95 \text{ bpm} (\sigma=1.61, \text{CV}=15.23)$. Those results were compared with medical heart rate monitoring device (Polar FT7) value of $75.43 \pm 1 \text{ bpm}$.

![Figure 4](image)

**Figure 4.** The periodically changes of the interference patterns on the screen at (a)-(f) 0.04 s, 0.12 s, 0.28 s, 0.32 s, 0.36 s and 0.40 s, respectively.

![Figure 5](image)

**Figure 5.** Variation of ROI positions on the x-axis as a function of frame number.

| Period number | Heart rate: BM (bpm) | Heart rate: OF (bpm) | Heart rate: Polar FT7 (bpm) |
|---------------|----------------------|----------------------|-----------------------------|
| 1             | 83.33                | 75.00                | 75                          |
| 2             | 68.18                | 68.18                | 74                          |
| 3             | 83.33                | 93.75                | 75                          |
| 4             | 68.18                | 68.18                | 75                          |
| 5             | 68.18                | 75.00                | 76                          |
| 6             | 68.18                | 68.18                | 77                          |
| 7             | 83.33                | 83.33                | 76                          |
| Average       | 74.67                | 75.95                | 75.43                       |
| Error (%)     | 1.01                 | 0.69                 | 0.00 (reference)            |

**Table 1.** Comparison of heart rates of BM and OF techniques with the reference values (Polar FT7).

5. Conclusions

The optically remote noncontact heart rates sensing technique using BM and OF techniques to analyse the periodically changes of the interference patterns were reported in this research. The results obtained from both techniques were compared with medical heart rate monitoring device. The errors from BM and OF techniques were found to be 1.01% and 0.69%, respectively.
6. Acknowledgments
I would like to express my sincere gratitude to Professor Dr. Pichet Limsuwan and Dr. Surapon Boonduang for their support and guidance throughout this research. Also thanks to Ms. Sunisa Jitsoonthornchaiyakul, Ms. Awika Saengwiman and Mr. Ekkaphop Ketsombun for teaming this research experiment.

References
[1] Tortora G J and Derrickson B H 2009 Principles of Anatomy and Physiology vol 12 ed Roesch B (USA) pp 780
[2] Metkar S and Talbar S 2013 Motion Estimation Techniques for Digital Video Coding vol 1 (New York: Springer) pp 16
[3] Yun Q S and Huifang S 2008 Image and Video Compression for Multimedia Engineering: Fundamentals, Algorithms, and Standards vol 2 ed P A Laplante (USA) pp 290 – 291
[4] Paragios N, Chen N and Faugeras O 2005 Mathematical Models in Computer Vision: The Handbook vol 1 (New York: Springer) pp 239 – 241
[5] Polar Electro Oy 2010 Polar FT7 User Manual vol 1 (Finland) pp 17