1. Tomasz SZABAŁA[2], 2. Andres VEJAR[1,2]

University of Economics and Innovation in Lublin (1), Research and Development Center Netrix S.A. (2)
ORCID: 1. 0000-0001-7827-7577; 2. 0000-0002-2041-0387

doi:10.15199/48.2023.01.57

Exploratory Study on Remote Photoplethysmography using Visible Light Cameras

Streszczenie. *Za pomocą kamer wideo w świetle widzialnym można oszacować tętno serca, śledząc zmiany intensywności obrazu wytwarzanego przez zmiany objętości krwi w tkance mikronaczyniowej. Oszacowanie to zapewnia technika pomiarowa zwana fotopletyzmografią zdalną (RPPG). W tym badaniu badamy akwizycję danych z RPPG przy użyciu standardowych kamer wideo używanych w komputerach osobistych.*

Abstract*. With visible light video cameras, it is possible to estimate the cardiac pulse, tracking the intensity changes in the image produced by the blood volume variations in the microvascular tissue. This estimation is provided by a measuring technique called remote photoplethysmography (RPPG). In this study we explore the data acquisition of the RPPG using standard video cameras used in personal computers (**Badanie eksploracyjne dotyczące zdalnej fotopletyzmografii z wykorzystaniem kamer światła widzialnego**).*

Słowa kluczowe: fotopletyzmogram, puls, światło widzialne kamery
Keywords: photoplethysmogram, heart rate, visible light cameras

Introduction

Photoplethysmography is a method for the detection of blood volume changes. This information allows further estimating of the pulse, and oxygen amount, among other important indicators of the cardiac system. The photoplethysmograph (PPG) refers to an optically estimated plethysmogram, which is, in general, a time series measurement of changes in volume in the body or for a particular organ. Remote PPG (RPPG) is a useful technique to obtain physiological data remotely, with the use of computer standard video equipment. It is also possible to test multiple parts of the human body.

There are two main trends in research [1-12]. The first one involves the use of high-performance video cameras in very well-controlled measurement environments. The second involves the use of computer-standard video cameras with the addition of online signal processing and machine-learning techniques to achieve proper measurements. The measurements are strongly dependent on ambient light and user activity. Therefore, the implementation of these systems continues to be a challenge for real-world applications.

Considering that the hardware required for RPPG is broadly available and that current computers are capable of very fast signal processing in CPU-GPU systems, it is very important to study the possibilities of RPPG technologies for the non-invasive and remote tracking of computer user biosignals.

Plethysmography and PPG

The term plethysmograph is a portmanteau of the Greek terms "plethysmos" which means "growth" and "graphein" which means "to write or to draw". In medicine, a plethysmograph is a measurement unit that evaluates volume changes. Two important techniques in plethysmography are used to track cardiorespiratory indicators: respiratory inductance plethysmography (RIP) and photoplethysmography (PPG). RIP measure the chest movement using bands with a coil that covers the chest and the abdomen. In RIP, the data acquisition is performed by comparing the inductive response of the coil with respect to its shape (extended or contracted). The coil is connected to an electrical oscillator that provides the base excitation signal. RIP can track pulmonary ventilation and respiration activity with respect to the inductance of the belt.

PPG is primarily used to identify and track changes in blood volume and flow product of cardiac activity. PPG can use low-intensity infrared (IR) light. Light can traverse biological tissues, and its absorption varies in blood-rich areas where venous or arteries are present with respect to other soft tissues such as muscle and adipose tissue or hard tissues such as bones.

From the data acquisition point of view, the light absorption in the skin is higher in blood-rich areas, and the light intensity captured in the video frames will variate accordingly with respect to the blood content of the tissue. The intensity measured by the PPG device is proportional to the quantity of blood flowing through the blood vessels. In controlled environments, it is possible to detect minimal changes in blood volume. This method is not designed to measure blood volume directly.

The PPG signal can be decomposed to derive many important cardiac indicators, between them, the change in arterial blood volume with respect to heart activity, the change in venous blood volume that drives the PPG signal and a constant component that expresses the optical characteristics of the tissue.

There are various types of devices for plethysmography. The plethysmograph devices can be distinguished by the type of transducer used, principally:

- Water plethysmographs (uses water-filled cuffs or chambers) [12-16]
- Air plethysmographs (uses air-filled cuffs) [17, 18]
- Strain gauge plethysmographs (rubber tubes) [19-24]
- Impedance plethysmographs (uses electrodes) [25-27]
- Photoelectric (uses photo sensors) [28, 29]

The term plethysmography was firstly described in [11], and it was the first scientific approach to PPG. It uses as an excitation light, an automobile headlight bulb powered by direct current, placed above the finger of the patient. The finger was located above a shielded photoelectric cell of the photo-emissive type. In order to prove the concept, the author measures the blood volume in the toe. In the late 1930’s, more works on PPG were published as the topic became very important, with multiple applications.

The popularity of the PPG consists of its characteristics, it relies on a simple setup, and it is non-invasive. Moreover, it does not require direct contact with the skin surface.

In this work, we will conduct RPPG measurements using visible light spectrum video cameras, differing from classic PPG measurements. The choice of the camera, in this case, is important, as the quality of the image matters for the quality of measurements conducted.

The other very important aspect is the light. It is important, that the ambient light is stable. Our measurements were conducted during daylight. The same type of measurements was performed using artificial light for comparison of the results.

RPPG measurement and data acquisition

To measure the RPPG we have used a standard laptop webcam, from Chicony Electronics, with a resolution of 1280x720 pixels. The main objective of our work is to estimate the heart rate using RPPG. After obtaining a robust estimation of the heart rate, we will extend this work to obtain more accurate dynamic measurements of cardiac activity.

The method of data acquisition consists of the following steps. First, the target patient sat in front of the computer camera, emulating standard desktop work. For this prototype study, we consider the still position of the user. Activity filtering can be considered later. The camera registers the data frames and fills the data buffers required for the spatial filters to operate. One time the buffer is filled, the spectral information of the video is extracted online, and an estimation of the heart rate is obtained.

The first step of the signal processing algorithm is the selection of the ROI (region of interest). To process the information, only the face information of the video frame is used, given that an important area of the face skin can be selected to volume. These variations are correlated with the heart rate. The ROI selection was achieved by a machine learning model to mask the face from the frames. Using the model, semantic segmentation of face and non-face pixels is obtained. To minimize the camera quantization error, the algorithm computes the spatial red, green and blue channels to extract the signal coming from the face.

Values from RBG channels are normalized temporally and projected to the skin tone. The temporal mean from the RGB channel of the skin is used to calculate the value of the RPPG. The heart rate estimation is computed from the skin RGB channels. A fast Fourier transform is applied to the RPPG signal to the desired frequency band. The frequency of the maximum energy in the spectrum represents the heart rate. In Figure 1, the pipeline schema for the face segmentation and tracking operation is presented.

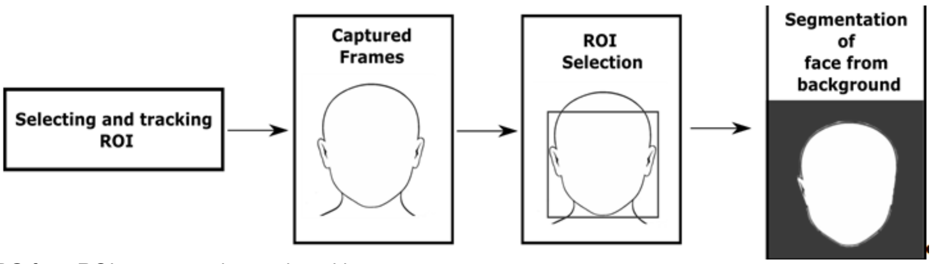
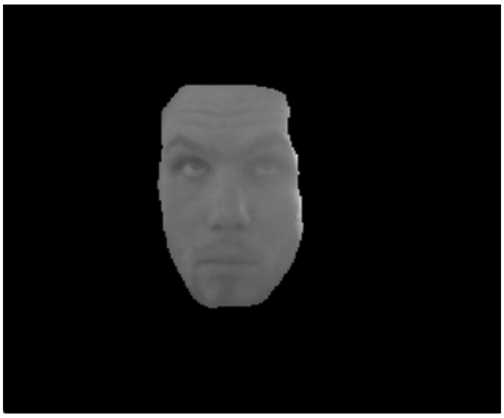


Fig..1. Pipeline for PPG face ROI segmentation and tracking

The results of RPPG data acquisition are presented in the following Figures. After the ROI selection, the face was segmented from the background in order to conduct proper measurement of blood volume. In Figure 2, the captured frame with face segmentation is presented.



Fige.2. PPG face segmentation.

In order for the algorithm to work correctly, it is necessary to keep the face in ambient, stable light. The light condition in the conducted algorithm testing was natural light coming from the back of the user through the window. No additional light sources were present near the user and camera, except the light from the monitor, which has no influence on the measurement during daylight. The second important element while measuring the PPG with the presented method is to keep the face in one position while the algorithm starts to obtain correct data for the face segmentation and tracking process. It is important for parameter learning at the beginning of the data acquisition.

For proper measurement results, the face needs to be tracked for the whole time during the measurement process in the same position and angle. Small movements are allowed, but any rapid movement of the face will cause the algorithm to drastically change the RGB data under tracking, with a strong non-linear behaviour that generates false results.

In Figure 3, the time series of the average heart rate calculated from RPPG is presented.

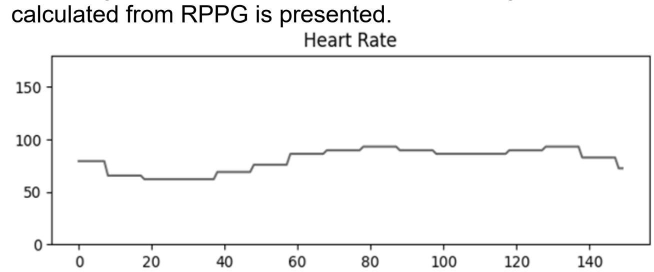


Fig.3. Average hear rate, estimated from RPPG data.

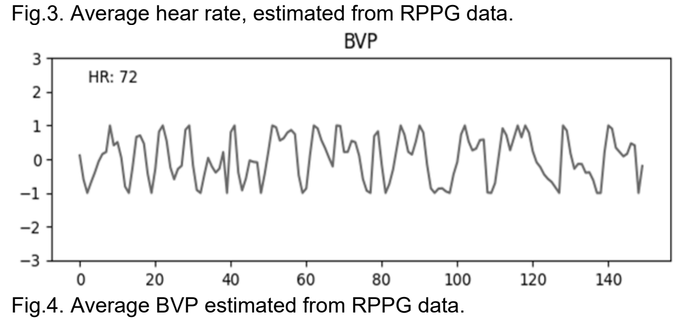


Fig.4. Average BVP estimated from RPPG data.

In Figure 4, an estimation of the blood volume pulse is presented.

The power spectral density for one snapshot of RPPG data is presented in Figure 5.

The average pulse of the measured user was around 70 beats per minute. In order to check if the algorithm works correctly, the measurement results were compared with the pulse oximeter measurements, which the user had placed on the finger during the process. The results of the RPPG are similar to the results of the pulse oximeter measurements. The differences in RPPG with respect to the pulse oximeter measurements can be explained by two main sources of error. The first and more important source of error in our measurement of RPPG is the user movements. The second source of error is the variations of ambient light. To reduce the first source of error, user activity, it is possible to update the data acquisition for faster cameras, including more frames per second to adapt the measurement to the user movement smoothly. To reduce the second source of error, it is possible to incorporate the estimation of ambient light into the model to correct the RGB channels with respect to standard illumination condition values.

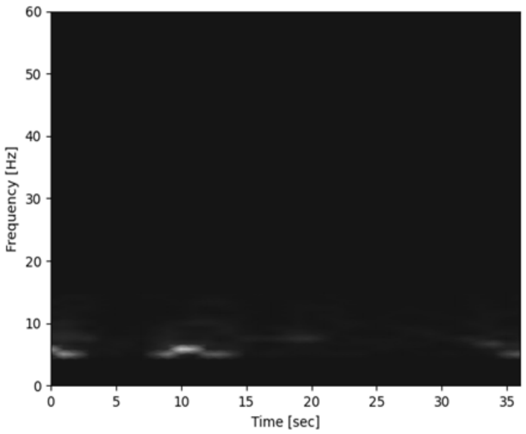


Fig..5. Power spectral density from RPPG data.

Conclusions

In this work, we have studied a method to obtain the important vital signals of a human patient without the requirement of equipping the patient with sensors and data acquisition devices. The measurements, using RPPG, can be conducted without any specialized equipment. The patient or user can use his own webcam to track their blood volume, pulse and hear rate. The use of RPPG allows for non-contact and simple measurements that can be used on a daily basis to track user vitals. For example, it is possible to track the user's heart rate during the exploration of a website or when the user interacts with software to provide insight into software user experience data. There are many methods to estimate cardiac data from RPPG signals, and newer and high-performing algorithms are still being actively developed. The influence of ambient light is important while conducting RPPG measurements, as the relationship between correct RPPG measurements and proper ambient light can be verified with the experimental data. Currently, the RPPG signals are rough estimates of the ECG signal data, but the video acquisition technology will improve the gap between RPPG and ECG measurements.

***Authors**: inż. Tomasz Szabała, Research and Development Center Netrix S.A, ul. Związkowa 26, 20-148 Lublin e-mail: tomasz.szabala@netrix.com.pl; dr inż. Andres Vejar, University of Economics and Innovation in Lublin , Research and Development Center Netrix S.A., ul. Związkowa 26, 20-148 Lublin, e- mail: andres.vejar@netrix.com.pl.*

REFERENCES

[1] Rymarczyk T., Kłosowski G., Hoła A., Sikora J., Tchórzewski P., Skowron Ł., Optimising the Use of Machine Learning Algorithms in Electrical Tomography of Building Walls: Pixel Oriented Ensemble Approach, Measurement, 188 (2022), 110581.

[2] Koulountzios P., Rymarczyk T., Soleimani M., Ultrasonic Time-of-Flight Computed Tomography for Investigation of Batch Crystallisation Processes, Sensors, 21 (2021), No. 2, 639.

[3] Kłosowski G., Rymarczyk T., Niderla K., Rzemieniak M., Dmowski A., Maj M., Comparison of Machine Learning Methods for Image Reconstruction Using the LSTM Classifier in Industrial Electrical Tomography, Energies 2021, 14 (2021), No. 21, 7269.

[4] Rymarczyk T., Król K. Kozłowski E., Wołowiec T., Cholewa-Wiktor M., Bednarczuk P., Application of Electrical Tomography Imaging Using Machine Learning Methods for the Monitoring of Flood Embankments Leaks, Energies, 14 (2021), No. 23, 8081.

[5] Majerek D., Rymarczyk T., Wójcik D., Kozłowski E., Rzemieniak M., Gudowski J., Gauda K., Machine Learning and Deterministic Approach to the Reflective Ultrasound Tomography, Energies, 14 (2021), No. 22, 7549.

[6] Kłosowski G., Rymarczyk T., Kania K., Świć A., Cieplak T., Maintenance of industrial reactors supported by deep learning driven ultrasound tomography, Eksploatacja i Niezawodnosc – Maintenance and Reliability; 22 (2020), No 1, 138–147.

[7] Gnaś, D., Adamkiewicz, P., Indoor localization system using UWB, Informatyka, Automatyka, Pomiary W Gospodarce I Ochronie Środowiska, 12 (2022), No. 1, 15-19.

[8] Styła, M., Adamkiewicz, P., Optimisation of commercial building management processes using user behaviour analysis systems supported by computational intelligence and RTI, Informatyka, Automatyka, Pomiary W Gospodarce I Ochronie Środowiska, 12 (2022), No 1, 28-35.

[9] Korzeniewska, E., Krawczyk, A., Mróz, J., Wyszyńska, E., Zawiślak, R., Applications of smart textiles in post-stroke rehabilitation, Sensors (Switzerland), 20 (2020), No. 8, 2370.

[10] Sekulska-Nalewajko, J., Gocławski, J., Korzeniewska, E., A method for the assessment of textile pilling tendency using optical coherence tomography, Sensors (Switzerland), 20 (2020), No. 13, 1–19, 3687.

[11] Alrick B. Hertzman., Photoelectric Plethysmography of the Fingers and Toes in Man, Proceedings of the Society for Experimental Biology and Medicine, *SAGE Journals*, 37 (2016), No. 3, 529-534.

[12] Lavoisier P, Barbe R, Gally M. Validation of a continuous penile blood-flow measurement by pulse-volume-plethysmography. International J Impotence Res., 14 (2002), No. 2.116–20.

[13] Unno N, Inuzuka K, Mitsuoka H, Ishimaru K, Sagara D. Automated Bedside Measurement of Penile Blood Flow Using Pulse-Volume Plethysmography. Surgery Today, 36 (2006), No. 3, 257–61.

[14] Kawakami Y, Menkes H, DuBois A. A Water-Filled Body Plethysmograph for the Measurement of Pulmonary Capillary Blood Flow during Changes of Intrathoracic Pressure. J Clin Invest., 49 (1970), 1237–51.

[15] Hyde R. Cowbird Research and Measuring Pulsatile Diffusing Capacity. Am J Respir Crit Care Med. 2002. 165.

[16] Horwitz D, Patel D. Maximal hand blood flow in hypertensive and normal subjects. Am J Cardiol., 5 (1985), No. 4, 418–22.

[17] Criado E, Farber M, Marston W, Daniel P, Burnham C, Keagy B. The role of air plethysmography in the diagnosis of chronic venous insufficiency. J Vasc Surg., 27 (1998), No. 4, 660–70.

[18] Weingarten M, Czeredarczuk M, Scovell S, Branas C, Mignogna G, Wolferth C. A correlation of air plethysmography and color-flow-assisted duplex scanning in the quantification of chronic venous insufficiency. J Vasc Surg., 24 (1996), No. 5, 750–4.

[19] DeSanctis M, Cesarone M, Incandela L, Belcaro G, Acerbi G. Methods of Evaluation and Quantification of Microangiopathy in High Perfusion Microangiopathy(Chronic Venous Insufficiency and Diabetic Microangiopathy) J Cardiovasc Pharmacol Ther.,7 (2002), No. 1,S3–S6.

[20] Rimaud D, Boissier C, Calmels P. Evaluation of the Effects of Compression Stockings Using Venous Plethysmography in Persons With Spinal Cord Injury. J Spinal Med., 31 (2008), No. ,202–7.

[21] Nicolaides A. Investigation of Chronic Venous Insufficiency. Circulation,102 (2000), e126–e63.
[22] Mannarino E, Pasqualini L, Menna M, Maragoni G, Orlandi U. Effects of Physical Training on Peripheral Vascular Disease: A Controlled Study. Angiology. 40 (1989), No. 1, 5–10.
[23] Maskell N, Meecham Jones D, Prior J, Butland R. The use of automated strain gauge plethysmography in the diagnosis of deep vein thrombosis. Brit J Radiol., 75 (2002), 648–51.
[24] Croal S, Birkmyrea J, McNallya M, Hamiltona C, Mollana R. Strain gauge plethysmography for the detection of deep venous thrombosis. J Biomed Eng., 15 (1993), No. 2, 165–39.
[25] Costeloe K, Rolfe P. Continuous Limb Blood Flow Estimation in the Newborn Using Electrical Impedance Plethysmography. Pediatric Res., 14 (1980), No. 9, 1053–60.
[26] Lukaski H, Johnson P, Bolonchuk Wa, Lykken G. Assessment of fat-free mass using bioelectrical impedance measurements of the human body. A J Clin Nutr., 41 (1985), 810
[27] Nyboer J, Murray P, Sedensky J. Blood-flow indices in amputee and control limbs by mutual electrical impedance plethysmography. Am Heart J., 87 (1974); No. 6, 704–10.
[28] Ubbink T. Toe Blood Pressure Measurements in Patients Suspected of Leg Ischaemia: A New Laser Doppler Device Compared with Photoplethysmography. European Journal of Vascular and Endovascular Surgery, 27 (2004), 629–34.
[29] Lees T, Lambert D. Patterns of venous reflux in limbs with skin changes associated with chronic venous insufficiency. British Journal of Surgery, 80 (1993), No. 6, 725–8.