UDC 612.216

O.K. Bodilovskyi
National Technical University of Ukraine “Kyiv Polytechnic Institute”,
off. 423, Politekhnichna Str., 16, Kyiv, 03056, Ukraine.

Non-contact respiration monitoring using optical sensors

The main goal of this paper is to develop classification of non-contact respiration monitoring approaches and proposal of structure for system with facial artifacts rejection. All available techniques were divided into two main groups: based on reconstruction of respiration from 3-D image of object and based on 2-D image processing of techniques. Structure of system for respiration monitoring using optical sensors with facial artifacts removing was developed. New approach allows improving of respiration monitoring for objects in supine position and in a sitting position. References 26, figures 16.

Keywords: *non-contact measurements, non-contact respiration monitoring, respiration monitoring, breathing monitoring, mimic artefacts, optical flow.*

Introduction

Monitoring of vital parameters such as heart rate and breathing parameters is an important task for medical scientists and engineers. Today’s medicine has good results in vital parameter estimation with invasive methods. Such methods typicaly involve contact to patient’s body, and require preliminary patient preparation which might not be convenient for patients and medical personnel in various clinical situations.

Respiration monitoring is an essential aspect in removal of moving artifacts for computer tomography [1], magnetic resonance imaging [2], image-guided radiation therapy [3], in neonatal applications [4], in monitoring applications for elderly people [5] and for automotive and aviation applications. Significant efforts are focused on the design of non-contact real-time breathing monitoring systems. Absence of direct contact between patient and monitoring device does not deliver discomfort and extends the areas of possible applications. There are plenty of approaches to noncontact respiration monitoring, such as ultrasonic, radar-based, capacitive ECG-based etc., but the most promising are the techniques based on the analysis of natural images of patients under monitoring, which are easily achievable. This is due to the wide availability of cameras, low cost and good operability.

The main goal of this work is to give thorough review of optical systems for respiration monitoring, and to propose the new method for improving existent solutions. The new design of non-contact respiration monitoring system is developed, in which the unit for artifact removal is included. The paper is organized as follows. In first section, techniques of respiration monitoring with 3-D scanning sensors are described. Second section presents monitoring approaches using 2-D image processing techniques. In the third section, the new structure of respiration monitoring system is proposed and justified.

1. General approaches to respiration monitoring in optical domain

If detection in optical domain is used for retrieval of respiration parameters, the movements of human body are usually thought to be directly connected to respiration. To detect respiration, the system should be designed to reconstruct body surface movement from the video sequence, and to estimate the magnitude of surface excursions in real time. Techniques of respiration monitoring differ by the general approach, which is used to extract movements.

In this paper, we propose to divide all optical methods into two groups depending on the dimensionality of captured data used for respiration extraction (Fig. 1).

In the first approach, reconstruction of respiration from 3-D image of object is used. It requires a specialized hardware, such as stereoscopic cameras and/or additional lightening equipment. This approach can be subdivided into two classes, first one using stereoscopic imaging, the second one based on projection methods.

Second approach is based on 2-D image processing techniques with using a single optical sensor, and can be subdivided into optical flow methods and frame subtraction methods.

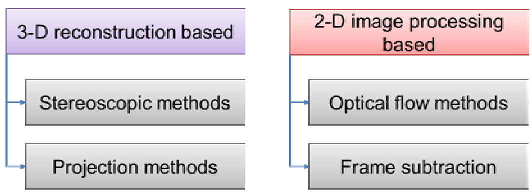

Fig. 1. Proposed classification of respiratory monitoring by techniques

 ISSN 1811-4512. ElectronComm 2014, Vol. 19, №1(78)

2. 3-D reconstruction based methods

Many kinds of systems for 3-D objects scanning are available in the market [6]. The taxonomy of optical 3-D scanners is given in Fig 2. In biomedical applications it is reasonable to use non-contact systems based on reflective principles. This approach provides patient's comfort and has no influence on his conditions. Two techniques of 3-D reconstruction are employed for respiration monitoring in most cases. Passive stereoscopic method based only on acquisition of reflected light from external sources, and active method called an active triangulation based on projection of specific markers on object before acquisition.

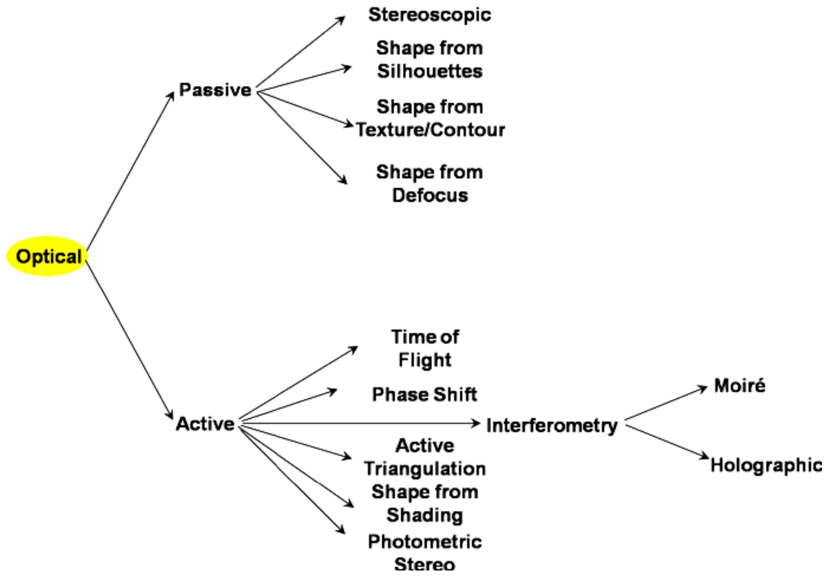

Fig. 2. An optical 3-D scanner taxonomy [6]

2.1. Stereoscopic methods of respiratory monitoring

Stereoscopic system contains two or more cameras that capture video of the same scene from different locations. It is possible to estimate distance to the object using the system demonstrated in Fig. 3. Depth of 3-D image is directly proportional to focal length of camera lense f and distance between cameras optical axes b, and inversely proportional to disparity of the same object point in pixels d: $depth = f \times (b/d)$.

The points of object for different images of the same scene should be robustly identified for correct 3-D reconstruction.

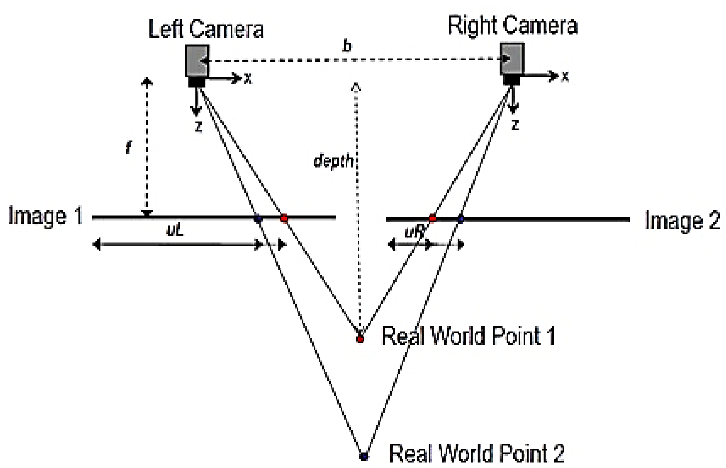

Fig. 3. Stereoscopic system

2.2. Projection-based systems for respiration monitoring

The main difference of active systems is the usage of light emmiter to create auxillary projection markers on object surface (Fig. 4). 3-D position of spot on the object's surface can be computed as intersection between l_1 and l_2 by triangulation [6].

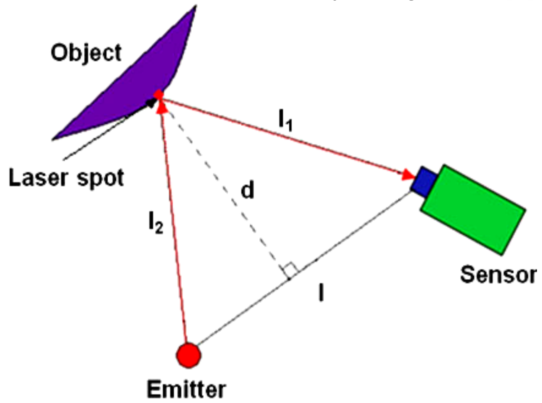

Fig. 4. Active triangle system [6]

2.3. Respiratory monitoring using 3-D techniques

Li et al. [3] used stereoscopic camera manufactured by Xigen for respiration tracking tasks in radiotherapy applications. Authors calculated 2-D depth image from 3-D reconstructed surface. After conversion of 3-D surface images to 2-D depth images, they used principal component analysis (PCA) to perform an unsupervised learning to extract different surface motion patterns from the 2-D depth image sequence. For the surface movements' patterns classification the support vector machine (SVM) technique is used (Fig. 5). Experiments have been conducted on phantom and 4 volunteers.

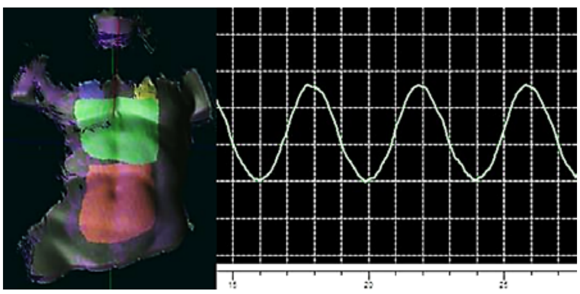

Fig. 5. The surface of the phantom (left) and the average first eigenvector motion with time (right) [3]

The majority of researchers [5], [7]–[9] uses active 3-D systems based on single CCD camera and fiber grating device (FGD). The FG device generate field of dots or stripes for three-dimensional surface of object reconstruction Fig. 7.

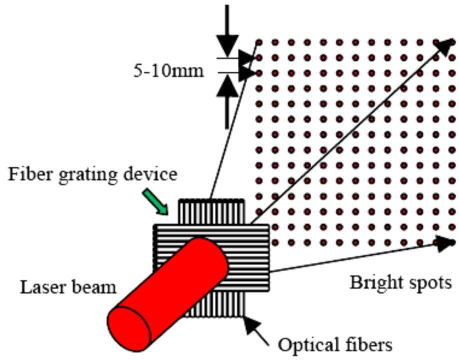

Fig. 7. Fiber grating device and dot-pattern [9]

FG devices are available on the market, Aoki et al. [8] used solution manufactured by Sumitomo Osaka Cement Co, ltd.

Appearance of common construction of experimental system shown in Fig. 8. System included bed with overhead support, where CCD camera and FGD are installed. In the most cases, resolution of CCD cameras was equal to 640x480 pixels.

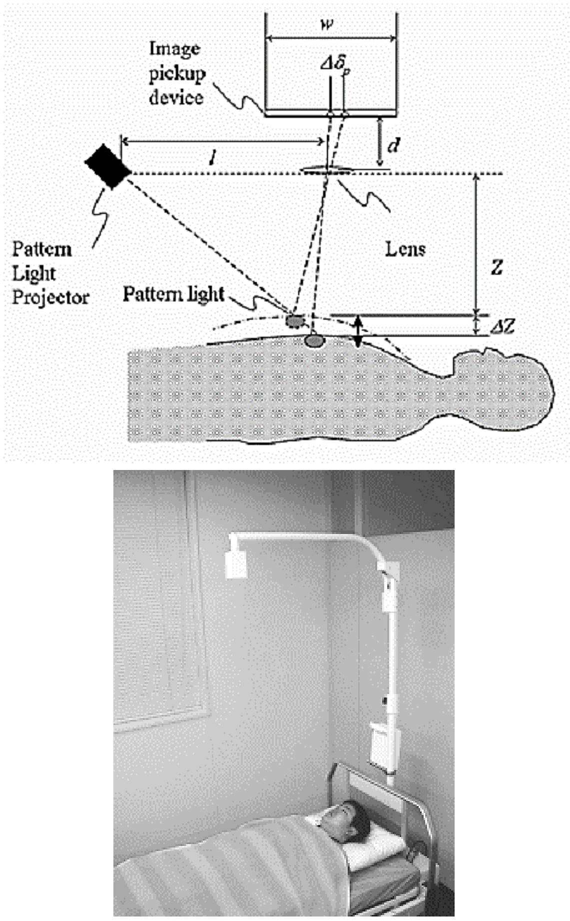

Fig. 8. Optical scheme of active triangle respiration monitoring system [8]

The relationship between vertical motion, represented by a symbol ΔZ, in the thoracicoabdominal part and shift length of the pattern light, denoted by a symbol d, in the image is given by following equation:

$$\Delta\delta = \frac{\Delta Z}{Z(Z-\Delta Z)} dl$$

where Z is the vertical distance from the height, at which the sensor was installed, to the body surface, d is the focal distance of lens, and l is the horizontal distance from the center of lens to the FG element. Thus the measurement principle of this method is based on the triangulation [5].

Aoki et al. [5], [8] used active triangle system for respiration parameters obtaining (Fig. 6). Authors have shown that waveforms measured by spirometer correspond to the respiratory flow measured by non-contact method. The same authors achieved better results with stripe projections then in the case of dot field projections [8]. They also obtained similar results with and without top covered quilt.

Povsic et al. [10] proposed non-contact real-time system for teaching and correcting respiration. Tamagawa et al. [9] presented system based on active triangle system for respiration estimation during tomography examination.

The Kinect system (9) for 3-D reconstruction is prevalent as well. Kinect was initially developed as gaming device but this system is used in respiratory applications [11]–[13]. Kinect includes RGB camera and couple of IR projector and IR camera, which are used for estimation of depth distance. System captures depth map of image with 320x240 pixel resolution. Yu et al. [14] developed Kinect-based system for monitoring position, body movements, and breathing rate during sleep.

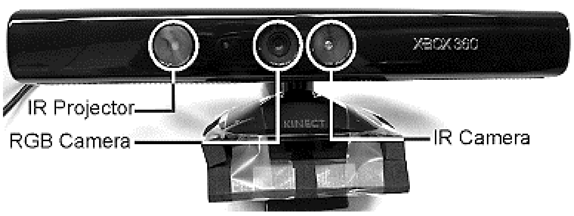

Fig. 9. Microsoft Kinect system [13]

Lodovico et al. [15] and Povsic et al. [10] proposed complex systems for whole human trunk surface vizualization during respiration analysis.

Systems in Figures 10 and 11 allow calculation of not only respiratory rate but also of expiratory volume.

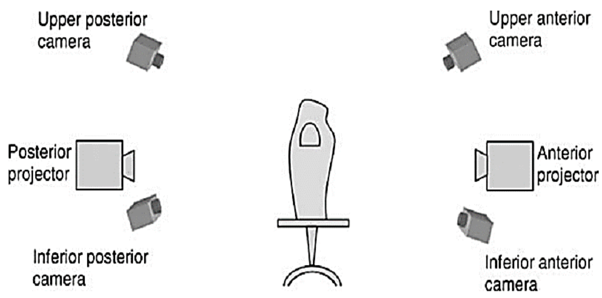

Fig. 10. Experimental setup with four cameras and two projectors [15]

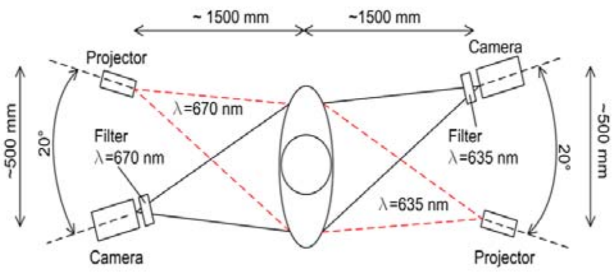

Fig. 11. Experimental setup with two cameras and two projectors

3. 2-D reconstruction based methods

Systems with 2-D reconstruction of respiration use single camera to capture video from the object, and consequent processing of two-dimensional images for localization of the object points.

2-D techniques employ single optical sensor for image acquisition. Sensors with various wavelength range can be used. Visible range cameras and near infrared cameras are used usually for respiration monitoring. Both types of cameras can be manufactured by CCD or CMOS technology. Modern CCD and CMOS sensors have comparable characteristics but CMOS is inexpensive and has lower power consumption. Therefore, CMOS cameras are usually used for general purpose and costumer electronics (web-cams, smartphones, etc.) and CCD are used in scientific and industrial applications.

Visible range cameras for respiration monitoring with good scene illumination can be employed. In the work [16], a system of NIR camera and NIR projector are implemented for the respiration monitoring in the scene with low brightness (monitoring during night). Fig. 12 shows sample frame of night respiration monitoring of patient in supine position.

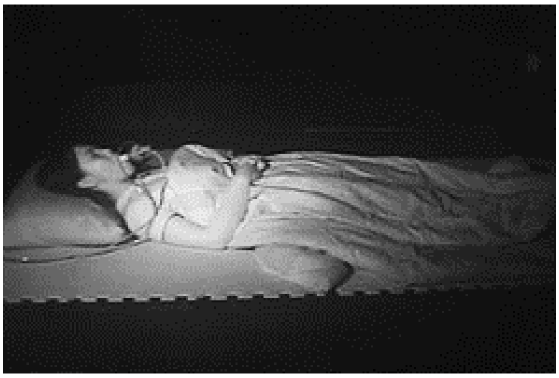

Fig. 12. Sample image captured with a near-infrared camera [16]

3.1. Respiration extraction by optical flow estimation

The most widespread technique that implements object movement estimation in video sequences is based on assessment of optical flow coming from the patient. For optical flow estimation, a few assumptions have to be accepted. First is that intensity of pixel for the same object on the video does not change between consecutive frames (1). This means that one gets the same intensity of the pixel on the next frame and this pixel is only shifted by u_x and u_y distance in x and y direction respectively.

$$I(x,y,t) = I(x+u_x, y+u_y, t+1) \qquad (1)$$

Consider pixel $I(x,y,t+1)$ and its copy $I(x,y,t)$ displaced by $\vec{u}$, where $\vec{u} = \begin{bmatrix} u_x \\ u_y \end{bmatrix}$ is two dimensional magnitude of displacement value (2).

$$I(x,y,t+1) = I(x,y,t) + \vec{u}\nabla I(x,y,t) \qquad (2)$$

$$I(x,y,t) - I(x,y,t+1) + \vec{u}\nabla I(x,y,t) = 0 \qquad (3)$$

$$\frac{\partial I(x,y,t)}{\partial t} + \vec{u}\nabla I(x,y,t) = 0 \qquad (4)$$

$$\frac{\partial I(x,y,t)}{\partial t} + u_x\frac{\partial I(x,y,t)}{\partial x} + u_y\frac{\partial I(x,y,t)}{\partial y} = 0 \qquad (5)$$

Expression (3) has been obtained using Taylor series expansion and ignoring high-order terms. Since only one time instance lies between two consecutive frames, the $I(x,y,t) - I(x,y,t+1)$ part of equation (3) can be regarded as time derivative $\frac{\partial I(x,y,t)}{\partial t}$ of pixel intensity for frame $I(x,y,t)$. Equation (5) was obtained after removing the gradient expression in (4). Equation (5) is called 2-D Motion Constraint Equation or Gradient Constraint. Motion Constraint Equation has no solutions because we have one equation and two unknowns. For solving this equation, one should assume that neighboring pixels have the same shift and consequently have the same magnitude of displacement $\vec{u}$.

Having this assumption accepted, it is possible to solve system of equation (6) where there are two unknowns and many equations (depend on chosen window size). $I_x(p_n)$ and $I_y(p_n)$ are spatial derivatives and $I_t(p_n)$ is time derivative of each pixel p_n.

$$\begin{bmatrix} I_x(p_1) & I_y(p_1) \\ I_x(p_2) & I_y(p_2) \\ \vdots & \vdots \\ I_x(p_n) & I_y(p_n) \end{bmatrix} \begin{bmatrix} u_x \\ u_y \end{bmatrix} = -\begin{bmatrix} I_t(p_1) \\ I_t(p_2) \\ \vdots \\ I_t(p_n) \end{bmatrix} \qquad (6)$$

There are many approaches to solve system (6) but the most widespread are Lukas-Kanade [17] and Horn-Schunk [18] methods of optical flow estimation. Both methods assess displacement magnitude $\vec{u}$ which minimizes error (7) for Lukas-Kanade and (8) for Horn-Schunk algorithm.

$$E(u_x,u_y) = \sum_{i,j} g(x_i,y_j) \times \\ \times \left[u_x\frac{\partial I(x,y,t)}{\partial x} + u_y\frac{\partial I(x,y,t)}{\partial y} + \frac{\partial I(x,y,t)}{\partial t} \right]^2 \qquad (7)$$

where $g(x_i,y_j)$ – two-dimensional Gaussian function.

$$E(u_x,u_y)=\iint\left[u_x\frac{\partial I(x,y,t)}{\partial x}+u_y\frac{\partial I(x,y,t)}{\partial y}+\frac{\partial I(x,y,t)}{\partial t}\right]^2dxdy+$$
$$+\lambda\iint\left\{\left(\frac{\partial u_x}{\partial x}\right)^2+\left(\frac{\partial u_x}{\partial y}\right)^2+\left(\frac{\partial u_y}{\partial x}\right)^2+\left(\frac{\partial u_y}{\partial y}\right)^2\right\}dxdy \qquad (8)$$

Nakajima et al. [21], [22] used optical flow technique for estimation of human respiration parameters and posture changes. Authors proposed v^2 parameter for evaluation of movement using video sequence. Proposed system detects posture change and respiration of the subject in bed by observing chest or blanket movement.

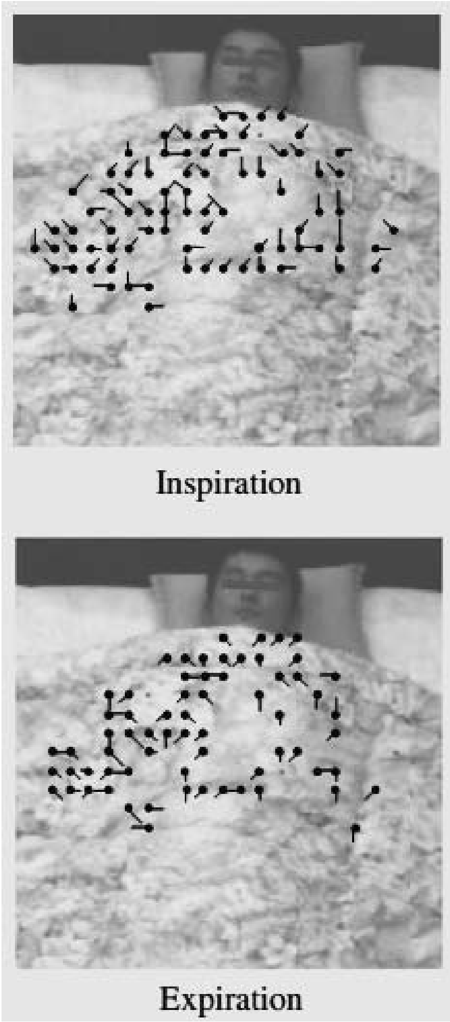

Fig. 13. Optical flow estimation for a subject in a supine position [22]

Kuo et al. [16] proposed a visual sleeping-respiration estimation system for monitoring and measuring the respiration parameters of sleeping people. Proposed system was built using near-infrared camera with a NIR projector. In their paper, authors evaluate new technique that combine Horn-Schunk optical flow estimation method and finite-state controlled hidden Markov model. The developed system can distinguish respiratory and non-respiratory body movement.

3.2. Respiration estimation by frame subtraction method

Frame subtraction that is usually applied for background removal [19], [20] can be used for respiration parameters estimation. The main feature of this method is removing regions that do not change from scene to scene. This technique allows deleting invariable background and leaving part of frame that has changed. Frame without background is computed using formula (9)

$$I(x,y,t)=I(x,y,t)-I(x,y,t+1) \qquad (9)$$

As seen from formula (9) the resulting frame $\Delta I(x,y,t)$ contains region that was changed, on the black background (invariable pixel are canceled). Example of two frames subtraction is shown in Fig. 14.

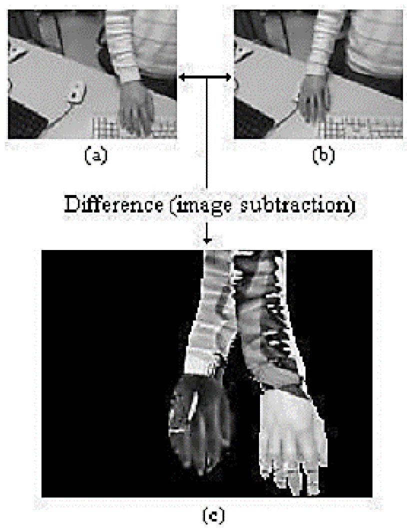

Fig. 14. Image subtraction: (a) and (b) are the original images used for subtraction; (c) the result of subtracting (b) from (a) [23].

Tan et al. [23] presents system for respiration monitoring based on frame subtraction technique. Authors developed system for assessment breathing parameters. They made experiments to study dependence of respiration monitoring quality on the distance between object and camera. Dependence of closing contrast and the monitoring accuracy was researched.

Weixing et al. [24] and Ji et al. [25] proposed system for animal respiration monitoring based on frame subtraction technique. The proposed techniques can be used for identifying animal health in real-time by detecting breathing parameters.

3.3. Artefact removal in 2-D respiration extraction techniques

Despite the availability of 3-D and 2-D systems for non-contact respiration monitoring, they are far from wide commercial use. In particular, these systems are prone to artifacts of various origin, such as patient and background movement, ambient light change etc. Thus they cannot be used in clinical conditions without the guidance of qualified personnel. For accurate respiration monitoring of patient in supine position the facial artifacts removal is important as well. Mimics and eyes movement are the usual source of artifacts that should be canceled, since they introduce substantial distortion in scene leading to decrease of quality of respiration parameters extraction.

Systems for non-contact respiration monitoring using single optical sensor include one camera with required wavelength range, hardware for collecting and processing raw sensor data and software for video processing. Software implements estimation of movement in video sequence (hence possibility to compute respiratory parameters). Typical block diagram of respiratory monitoring system is shown in Fig. 15

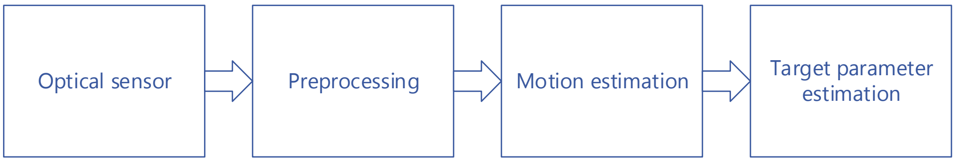

Fig. 15. Typical respiration monitoring system

In this paper, facial artifacts removing is proposed to improve existent systems. Separate additional block is included in the block diagram. This block implements face recognition and exclusion of the face region from image to be analyzed at next stage. Algorithm is based on optical flow technique for motion estimation and Viola–Jones algorithm [26] for face region localization, and following removal of this area from video frame. The proposed method allows to remove artifacts induced by mimics movement and eye blinking. Modified block diagram of proposed system is shown in Fig. 16.

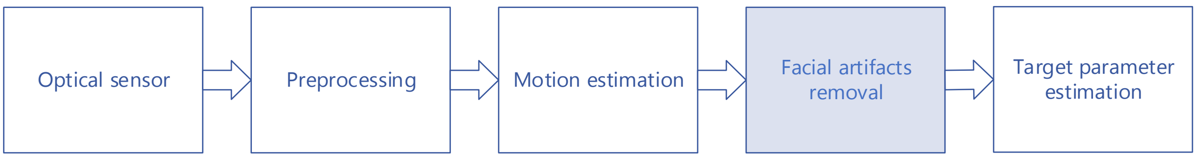

Fig. 16. Respiration monitoring system with facial artifacts removal

Procedure of data processing have the following stages: video flow capturing, motion estimation using optical flow technique, face recognition and removal of facial region from analysis, obtaining of respiration curve, target parameter calculation.

Conclusion

In this paper, the classification of respiration monitoring methods using optical sensors was proposed. Structure of respiration monitoring system with facial artifacts removing is developed, using the facial mimics and eyes blinking artefacts removal. New system can improve respiration monitoring for human positioned in frontal plane.

References

1. K. *R. Jones,* “A respiration monitor foe use with CT body scanning and other imaging techniques,” Br. J. Radiol., vol. 55, no. 655, pp. 530–533, Jul. 1982.
2. *R. Ehman, M. McNamara, M. Pallack, H. Hricak, and C. Higgins,* “Magnetic resonance im-

aging with respiratory gating: techniques and advantages," Am. J. Roentgenol., vol. 143, no. 6, pp. 1175–1182, Dec. 1984.

3. *T. Li, J. Geng, and S. Li,* "Automatic respiration tracking for radiotherapy using optical 3D camera," pp. 861804–861804, 2013.
4. *A. K. Abbas, K. Heimann, K. Jergus, T. Orlikowsky, and S. Leonhardt,* "Neonatal Non-contact Respiratory Monitoring based on Real-time Infrared Thermography," Biomed. Eng. OnLine, vol. 10, no. 1, p. 93, 2011.
5. *H. Aoki and K. Koshiji,* "Non-contact Respiration Monitoring Method for Screening Sleep Respiratory Disturbance Using Slit Light Pattern Projection," in World Congress on Medical Physics and Biomedical Engineering 2006, R. Magjarevic and J. H. Nagel, Eds. Springer Berlin Heidelberg, 2007, pp. 680–683.
6. *N. A. Borghese and S. Ferrari*, 3D Surface Reconstruction: Multi-Scale Hierarchical Approaches. Springer, 2012.
7. *I. Sato and M. Nakajima*, "Non-contact Breath Motion Monitor ing System in Full Automation," in Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the, 2005, pp. 3448–3451.
8. *H. Aoki, K. Koshiji, H. Nakamura, Y. Takemura, and M. Nakajima,* "Study on respiration monitoring method using near-infrared multiple slit-lights projection," in 2005 IEEE International Symposium on Micro-NanoMechatronics and Human Science, 2005, pp. 291–296.
9. *K. Tamagawa, K. Ogawa, and M. Nakajima*, "Detection of respiratory movement during SPECT/PET data acquisition," in 2002 IEEE Nuclear Science Symposium Conference Record, 2002, vol. 3, pp. 1571–1574 vol.3.
10. *K. Povšič, M. Fležar, J. Možina, and M. Jezeršek,* "Laser 3-D measuring system and real-time visual feedback for teaching and correcting breathing," J. Biomed. Opt., vol. 17, no. 3, p. 036004, Mar. 2012.
11. *H. Aoki, M. Miyazaki, H. Nakamura, R. Furukawa, R. Sagawa, and H. Kawasaki,* "Non-contact respiration measurement using structured light 3-D sensor," in 2012 Proceedings of SICE Annual Conference (SICE), 2012, pp. 614–618.
12. *M. Martinez and R. Stiefelhagen,* "Breath rate monitoring during sleep using near-ir imagery and PCA," in 2012 21st International Conference on Pattern Recognition (ICPR), 2012, pp. 3472–3475.
13. *J. Xia and R. A. Siochi,* "A real-time respiratory motion monitoring system using KINECT: Proof of concept," Med. Phys., vol. 39, no. 5, pp. 2682–2685, 2012.
14. *M.-C. Yu, H. Wu, J.-L. Liou, M.-S. Lee, and Y.-P. Hung,* "Multiparameter Sleep Monitoring Using a Depth Camera," in Biomedical Engineering Systems and Technologies, J. Gabriel, J. Schier, S. V. Huffel, E. Conchon, C. Correia, A. Fred, and H. Gamboa, Eds. Springer Berlin Heidelberg, 2013, pp. 311–325.
15. *G. F. Lewis, R. G. Gatto, and S. W. Porges,* "A novel method for extracting respiration rate and relative tidal volume from infrared thermography," Psychophysiology, vol. 48, no. 7, pp. 877–887, 2011.
16. *Y.-M. Kuo, J.-S. Lee, and P. Chung,* "A Visual Context-Awareness-Based Sleeping-Respiration Measurement System," IEEE Trans. Inf. Technol. Biomed., vol. 14, no. 2, pp. 255–265, 2010.
17. *B. D. Lucas and T. Kanade*, "An iterative image registration technique with an application to stereo vision.," in IJCAI, 1981, vol. 81, pp. 674–679.
18. *B. K. P. Horn and B. G. Schunck,* "Determining optical flow," Artif. Intell., vol. 17, no. 1–3, pp. 185–203, 1981.
19. *J. C. S. Jacques, C. R. Jung, and S. Raupp Musse,* "Background Subtraction and Shadow Detection in Grayscale Video Sequences," in 18th Brazilian Symposium on Computer Graphics and Image Processing, 2005. SIBGRAPI 2005, 2005, pp. 189–196.
20. *C. R. Jung,* "Efficient Background Subtraction and Shadow Removal for Monochromatic Video Sequences," IEEE Trans. Multimed., vol. 11, no. 3, pp. 571–577, 2009.
21. *K. Nakajima, A. Osa, and H. Miike*, "A method for measuring respiration and physical activity in bed by optical flow analysis," in Proceedings of the 19th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1997, 1997, vol. 5, pp. 2054–2057 vol.5.
22. *K. Nakajima, Y. Matsumoto, and T. Tamura*, "Development of real-time image sequence analysis for evaluating posture change and respiratory rate of a subject in bed," Physiol. Meas., vol. 22, no. 3, p. N21, Aug. 2001.
23. *K. S. Tan, R. Saatchi, H. Elphick, and D. Burke,* "Real-time vision based respiration monitoring system," in 2010 7th International Symposium on Communication Systems Net-

works and Digital Signal Processing (CSNDSP), 2010, pp. 770–774.
24. *Z. Weixing and W. Zhilei,* “Detection of porcine respiration based on machine vision,” in 2010 3rd International Symposium on Knowledge Acquisition and Modeling (KAM), 2010, pp. 398–401.
25. *B. Ji, F. Qin, and H. Liu,* “An Expression of Animal Abdominal Breathing Based on Intercept,” in 2012 International Conference on Biomedical Engineering and Biotechnology (iCBEB), 2012, pp. 716–719.
26. *P. Viola and M. J. Jones,* “Robust Real-Time Face Detection,” Int. J. Comput. Vis., vol. 57, no. 2, pp. 137–154, May 2004.

Поступила в редакцию 10 декабря 2013 г.

УДК 612.216

О.К. Боділовський

Національний технічний університет України “Київський політехнічний інститут”,

пр. Перемоги, 37, Київ-56, 03056, Україна.

Безконтактний моніторинг дихання з використанням оптичних сенсорів

Ціллю даної роботи є класифікація підходів до безконтактного моніторингу дихання і розробка структури системи моніторингу з усуненням артефактів міміки. Усі наявні методи були розділені на дві основні групи: методи на основі визначення дихання з 3-D зображення об'єкта і методи на основі 2-D обробки зображень. Була розроблена структура системи моніторингу дихання на основі оптичних сенсорів з можливістю видалення артефактів міміки. Новий підхід дозволяє покращити моніторинг дихання для об'єктів в положенні лежачи на спині і в позиції сидячи. Бібл. 26, рис. 16.

Ключові слова: *безконтактні вимірювання, безконтактний моніторинг дихання, моніторинг дихання, артефакти міміки, оптичний потік.*

УДК 612.216

О.К. Бодиловский

Национальный технический университет Украины “Киевский политехнический институт”,

пр. Победы, 37, Киев-56, 03056, Украина.

Бесконтактный мониторинг дыхания с использованием оптических датчиков

Целью работы является классификация подходов к бесконтактному мониторингу дыхания и разработка структуры системы мониторинга с устранением артефактов мимики. Все имеющиеся методы были разделены на две основные группы: методы на основе определения дыхания из 3-D изображения объекта и методы на основе 2-D обработки изображений. Была разработана структура системы мониторинга дыхания на основе оптических датчиков с возможностью удаления артефактов мимики. Новый подход позволяет улучшить мониторинг дыхания для объектов в положении лежа на спине и в позиции сидя. Библ. 26, рис. 16.

Ключевые слова: *бесконтактные измерения, бесконтактный мониторинг дыхания, мониторинг дыхания, артефакты мимики, оптический поток.*

Список использованных источников

1. *K. R. Jones.* (1982), “A respiration monitor foe use with CT body scanning and other imaging techniques,” Br. J. Radiol., vol. 55, no. 655, pp. 530–533, Jul.
2. *R. Ehman, M. McNamara, M. Pallack, H. Hricak, and C. Higgins.* (1984). “Magnetic resonance imaging with respiratory gating: techniques and advantages,” Am. J. Roentgenol., vol. 143, no. 6, pp. 1175–1182, Dec.
3. *T. Li, J. Geng, and S. Li.* (2013), “Automatic respiration tracking for radiotherapy using optical 3D camera,” pp. 861804–861804.

4. *A. K. Abbas, K. Heimann, K. Jergus, T. Orlikowsky, and S. Leonhardt.* (2011), “Neonatal Non-contact Respiratory Monitoring based on Real-time Infrared Thermography,” Biomed. Eng. OnLine, vol. 10, no. 1, p. 93.
5. *H. Aoki and K. Koshiji.* (2007), “Non-contact Respiration Monitoring Method for Screening Sleep Respiratory Disturbance Using Slit Light Pattern Projection,” in World Congress on Medical Physics and Biomedical Engineering 2006, R. Magjarevic and J. H. Nagel, Eds. Springer Berlin Heidelberg, Pp. 680–683.
6. *N. A. Borghese and S. Ferrari.* (2012), “3D Surface Reconstruction: Multi-Scale Hierarchical Approaches”. Springer, 2012.
7. *I. Sato and M. Nakajima.* (2005), “Non-contact Breath Motion Monitor ing System in Full Automation,” in Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the, Pp. 3448–3451.
8. *H. Aoki, K. Koshiji, H. Nakamura, Y. Takemura, and M. Nakajima.* (2005), “Study on respiration monitoring method using near-infrared multiple slit-lights projection,” in 2005 IEEE International Symposium on Micro-NanoMechatronics and Human Science, Pp. 291–296.
9. *K. Tamagawa, K. Ogawa, and M. Nakajima.* (2002), “Detection of respiratory movement during SPECT/PET data acquisition,” in 2002 IEEE Nuclear Science Symposium Conference Record, vol. 3, pp. 1571–1574 vol.3.
10. *K. Povšič, M. Fležar, J. Možina, and M. Jezeršek.* (2012), “Laser 3-D measuring system and real-time visual feedback for teaching and correcting breathing,” J. Biomed. Opt., vol. 17, no. 3, p. 036004, Mar.
11. *H. Aoki, M. Miyazaki, H. Nakamura, R. Furukawa, R. Sagawa, and H. Kawasaki.* (2012), “Non-contact respiration measurement using structured light 3-D sensor,” in 2012 Proceedings of SICE Annual Conference (SICE), Pp. 614–618.
12. *M. Martinez and R. Stiefelhagen.* (2012), “Breath rate monitoring during sleep using near-ir imagery and PCA,” in 2012 21st International Conference on Pattern Recognition (ICPR), Pp. 3472–3475.
13. *J. Xia and R. A. Siochi.* (2012), “A real-time respiratory motion monitoring system using KINECT: Proof of concept,” Med. Phys., vol. 39, no. 5, pp. 2682–2685.
14. *M.-C. Yu, H. Wu, J.-L. Liou, M.-S. Lee, and Y.-P. Hung.* (2013), “Multiparameter Sleep Monitoring Using a Depth Camera,” in Biomedical Engineering Systems and Technologies, J. Gabriel, J. Schier, S. V. Huffel, E. Conchon, C. Correia, A. Fred, and H. Gamboa, Eds. Springer Berlin Heidelberg, Pp. 311–325.
15. *G. F. Lewis, R. G. Gatto, and S. W. Porges.* (2011), “A novel method for extracting respiration rate and relative tidal volume from infrared thermography,” Psychophysiology, vol. 48, no. 7, pp. 877–887.
16. *Y.-M. Kuo, J.-S. Lee, and P. Chung*. (2010), “A Visual Context-Awareness-Based Sleeping-Respiration Measurement System,” IEEE Trans. Inf. Technol. Biomed., vol. 14, no. 2, pp. 255–265.
17. *B. D. Lucas and T. Kanade*. (1981), “An iterative image registration technique with an application to stereo vision.,” in IJCAI, vol. 81, pp. 674–679.
18. *B. K. P. Horn and B. G. Schunck*. (1981), “Determining optical flow,” Artif. Intell., vol. 17, no. 1–3, pp. 185–203.
19. *J. C. S. Jacques, C. R. Jung, and S. Raupp Musse*. (2005), “Background Subtraction and Shadow Detection in Grayscale Video Sequences,” in 18th Brazilian Symposium on Computer Graphics and Image Processing, 2005. SIBGRAPI 2005, Pp. 189–196.
20. *C. R. Jung.* (2009), “Efficient Background Subtraction and Shadow Removal for Monochromatic Video Sequences,” IEEE Trans. Multimed., vol. 11, no. 3, pp. 571–577.
21. *K. Nakajima, A. Osa, and H. Miike*. (1997), “A method for measuring respiration and physical activity in bed by optical flow analysis,” in Proceedings of the 19th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, vol. 5, pp. 2054–2057 vol.5.
22. *K. Nakajima, Y. Matsumoto, and T. Tamura.* (2001), “Development of real-time image sequence analysis for evaluating posture change and respiratory rate of a subject in bed,” Physiol. Meas., vol. 22, no. 3, p. N21, Aug.
23. *K. S. Tan, R. Saatchi, H. Elphick, and D. Burke*. (2010), “Real-time vision based respiration monitoring system,” in 2010 7th International Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP), Pp. 770–774.
24. *Z. Weixing and W. Zhilei*. (2010), “Detection of porcine respiration based on machine vision,” in 2010 3rd International Symposium on Knowledge Acquisition and Modeling (KAM), pp. 398–401.
25. *B. Ji, F. Qin, and H. Liu*. (2012), “An Expression of Animal Abdominal Breathing Based on Intercept,” in 2012 International Conference on Biomedical Engineering and Biotechnology (iCBEB), Pp. 716–719.
26. *P. Viola and M. J. Jones*. (2004), “Robust Real-Time Face Detection,” Int. J. Comput. Vis., vol. 57, no. 2, pp. 137–154, May.