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New Aspects in Respiratory Epithelium Diagnostics Using Virtual Instrumentation

Dušan KONIAR, Libor HARGAŠ, [1]Miroslav HRIANKA, [2]Peter BÁNOVČIN
[1]Department of Mechatronics and Electronics, Faculty of Electrical Engineering,
University of Žilina, Univerzitná 1, 010 26, Žilina, Slovak republic
[2]Clinic of Children and Youths, Faculty Hospital in Martin,
Kollárova 2, 036 01 Martin, Slovak republic
E-mail: dusan.koniar@fel.uniza.sk

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Abstract: Subject of interest is trajectory analysis of moving object. Object is represented by respiratory epithelium cilium. Cilium trajectory and another parameter – beating frequency – are very important parameters in respiratory apparatus diagnostics. Main method of motion detection is Geometric Matching and gray level variance capturing. Primary experiments were taken on video phantoms simulating cilia movement using two camera systems: Marlin and PONTOS. All the phantoms were processed in LabVIEW development environment. Article focuses on acquisition conditions, preprocessing of videosequences and basic measurement on acquired phantoms. *Copyright © 2009 IFSA.*

Keywords: Biomechanical system, Cilium, Trajectory, Image analysis, LabVIEW

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1. Cilium as Biomechanical System

Cilium is a very important part of mucus transport. There are ca. 200 cilias (6 μm long) on each epithelium cell. These structures are beating with frequency in range 17-30 Hz. Incurved cilias are unbending in effective stroke phase to move the mucus with their tops to larynx in lower parts and to pharynx in upper parts of respiratory apparatus.

Ciliated epithelium has 2 basic functions: accumulating a moving the mucus oral direction. This is done in two-phase cycle:

1. recovery stroke,
2. effective stroke.

This cycle is in Fig. 1 and described in [1].

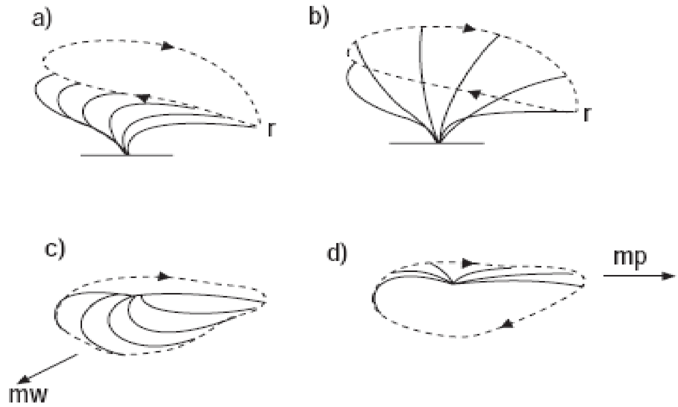

Fig. 1. Single phases of cilium beating cycle.

Acquired (secondary) or inherent (primary) pathologies of cilium causes dyskinesia or slows the beating. In this case, cilium movement is not synchronized and mucus with foreign particles and infects accumulates in respiratory apparatus. Primary ciliary dyskinesia (PCD) and cystic fibrosis belong to inherent – primary pathologies of respiratory apparatus. Secondary pathologies are caused by structural cilium changes.

2. Acquisition of Phantom Videosequences

In this phase of diagnostics we must set maximal frame rate (FPS) of used camera systems. For training and designing the software applications for analysis kinetics parameters some phantoms were made (movement of elastic fibre periodically oscillating on bright background). Using Marlin F-046B camera system we could set maximal FPS to 60.

For acquisition of another set of phantom videosequneces we used PONTOS camera system with FPS parameter going to 800. Both camera systems store image in 8 BPP depth (grayscale).

In Fig. 2 we can see both camera systems: digital camera PONTOS from Gom Ltd. company and Marlin F-046B.

Fig. 2. Digital camera systems PONTOS and Marlin.

There is a list of phantom videosequences (Fig. 3, Tab. 1) acquired with PONTOS system:

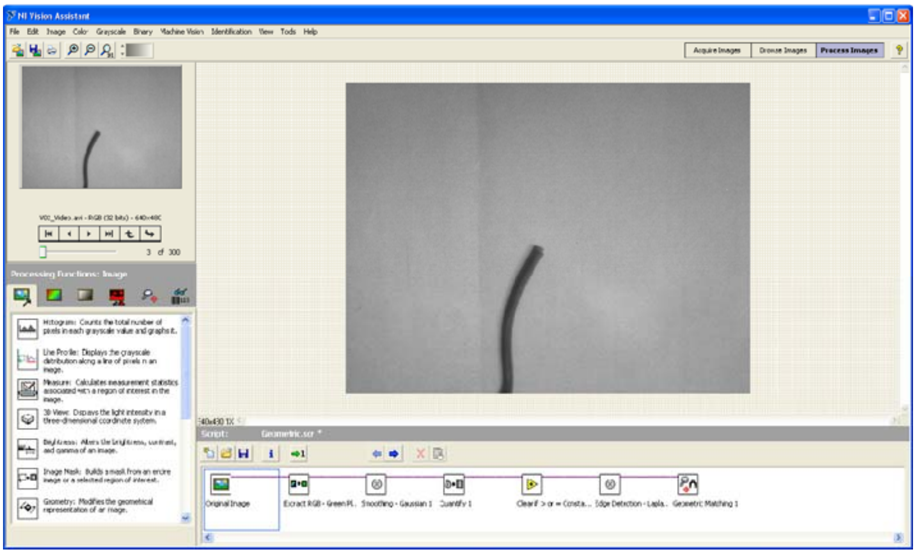

Fig. 3. Phantom videosequence in Vision Assistant environment.

Table 1. Parameters of acquired videosequences.

Phantom #	FPS
1	46
2	100
3	200
4	300
5	400

3. Object Detection and Kinetic Parameters Analysis Import

Geometric matching is technique used for quick localization of patterns in image with known description of mutual relations (shape, brightness...). This description is done by edge detection. Geometric matching is the key to many practical applications. In these applications, information about number or inherency (absence) of some patterns is very important. The most important phase in Geometrical matching technique is training the template.

Geometric matching is not only for recognition of one pattern (template), but it can detect few different patterns in one image using proper template training. This technique is based on edge information, so edge detection is good preprocessing step before matching. Some problems are with noise degraded images – we must use some noise filters for removing bogus edges [2], [3], [4].

In development environment LabVIEW and its module Vision Assistant we designed some scripts for preprocessing of videosequneces (raw format, AVI) and for object detection using Geometric matching algorithm.

For optimal smoothing and noise removal we used Gaussian convolution filter (5 x 5 kernel). Then we used image quantification for computing minimal, maximal and mean value of gray levels. These values were used in another preprocessing process. The main aim of this step was shadow removal caused by object in given conditions of illumination. Some results of preprocessing are shown in Fig. 4.

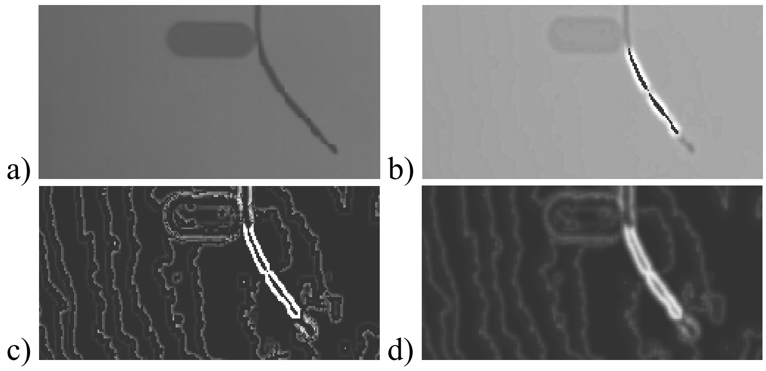

Fig. 4. Preprocessing of input images: a) original image; b) convolution; c) edge detection; d) Gaussian filter.

In the last phase of work Geometric matching was working with high score to 900 (90 % of similarity with template).

In the preprocessing step very important is setting up the brightness, contrast and gamma values. Proper template selection has a big influence on accuracy of object detection with matching technique. Cilium trajectory detection, its representation and classification is still in progress. Some results of matching detections are in Fig. 5. In trajectory detection we must set the offset parameter in matching algorithm. Offset represents the position in template which is considered in recognized object as point of trajectory. Usually we select the central pixel of bounding rectangle.

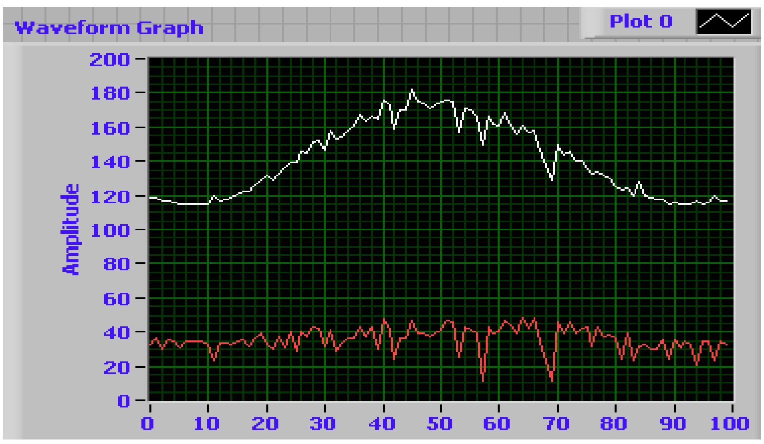

Fig. 5. Example of object motion trajectory.

4. Analysis of Frequency

For measurement of beating frequency we designed and improved method of intensity variance capturing. This method calculates mean value of grayscale level in selected region of interest (ROI) in each frame of videosequence. Using post-processing methods we can measure frequency domain parameters such as main frequency, other spectral components or beating cycle period. User can make interactive ROI selection on reference video frame with size k * l pixels and position of left upper corner [L; T]. Then mean gray level value on N-th frame is:

$$I_{avg}(N) = \frac{1}{k.l}\sum_{i=1}^{k}\sum_{j=1}^{l} f(i+T; j+L)(N) \tag{1}$$

This calculation is done on each frame and variance curve is made from each I_{avg} value. Beating cilium is crossing selected ROI and changes the intensity within: if cilium is dark object on bright background, then low values of intensity indicate position of cilium inside the ROI and high values indicate absence of the cilium in ROI.

Basic curve shows relation between intensity and number of frame. We can transform the horizontal axis to time axis, if we know frame rate (FPS or f_s) of acquired videosequence. Transformation formula is then:

$$T = N.\frac{1}{f_s} \tag{2}$$

We can improve accuracy of curve by increasing of FPS or some tools in preprocessing phase (histogram equalizing, contrast enhancement…). Example of intensity curve with transformed time axis in seconds is in Fig. 6.

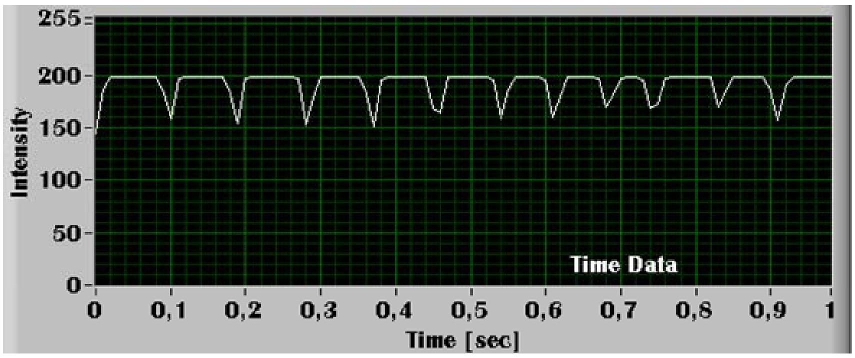

Fig. 6. Example of intensity variance curve.

Output format of videosequence has an influence on quality of analysis. The best for analysis are raw videosequences without information loss. Some compressed formats such as MPEG or DivX causes block effect, which suppresses fine image details.

On suitable parts of variance curve we apply Fast Fourier transform (FFT) for harmonic analysis. Main frequency and other spectral components of example curve are in Fig. 7. More about variation curve processing is in [5].

In signal processing, maximal frequency of acquired signal is set by Shannon-Koteľnik formula, where sampling frequency must be at least double value of maximal signal frequency. Maximal physiological value of cilia beating is ca. 30 Hz. It means that camera system must support at least 60 FPS. In image acquisition this relation between signal and sampling frequency is bigger, where optimal sampling frequency (frame rate) is about 300 FPS.

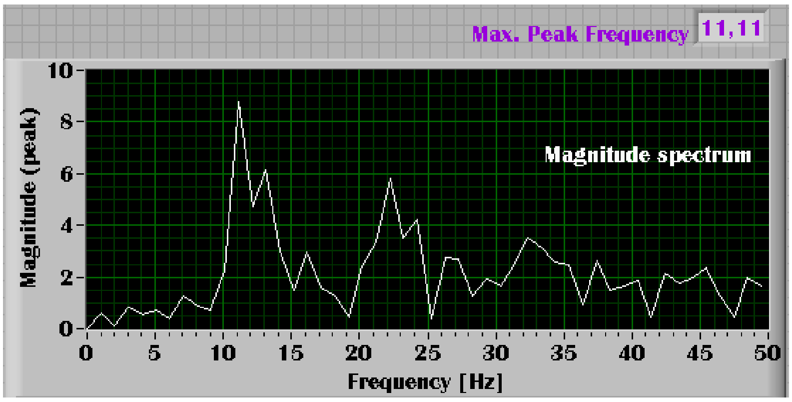

Fig. 7. Fourier analysis of variance curve.

Working with phantoms brings some assumes for work with real videosequences. For proper frequency measurement, selected ROI must content end part of cilium (top) and size of ROI must be not so big, when intensity curve has big gray value difference between two states (cilium inside / outside ROI) and steepness of curve is high.

5. Conclusions

Some phases of diagnostics of kinetic parameters of respiratory epithelium are in progress (especially trajectory capturing and its representation and classification). Measurement of beating frequency seems to be optimal for using gray level intensity variance curve processing.

Primary experiments were taken on phantom videosequences. In this phase, some basic algorithms were designed and trained.

With system PONTOS we acquired videosequences with higher frame rate (to 400 FPS), so matching techniques were working better and more reliable. Using virtual instrumentation development environment LabVIEW and its module Vision Assistant, we designed practical application for graphical representation of measured trajectories and frequency analysis.

At the second phase of work, we have acquired some real videosequences of respiratory epithelium in Faculty hospital in Martin. The future work would deal with finding of optimal preprocessing algorithms for real videosequences and applying of existing scripts for analysis on them.

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Guide for Contributors

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Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
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- Sensor instrumentation;
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