Sophisticated Measurement of Non-Electrical Parameters Using Image Analysis

Libor Hargaš, Dušan Koniar, Viktor Bobek, Stanislav Štofan, Miroslav Hrianka
Department of Mechatronics and Electronics
University of Žilina, Faculty of Electrical Engineering
Žilina, Slovakia
{Libor.Hargas, Dusan.Koniar, Viktor.Bobek, Stanislav.Stofan, Miroslav.Hrianka}@fel.uniza.sk

***Abstract*—Paper focuses on main topics in frequency measurement with high speed video camera. The system is designed as phantom measurement. Phantom is realized with linear motor and controlled by DSP processor. The motor frequency is measured using image acquisition. This acquisition is done by high speed video camera. The sequences of captured images are processing with image analysis. Image analysis and other algorithms are done by virtual instrumentation using LabVIEW. The parameters of measured objects give relevant information about frequency and trajectory. This system can be used in sophisticated measurements in many educational, research and industrial applications where moving objects of investigation can't be equipped with sensors of kinematic parameters.**

Keywords-image processing, virtual instrumentation, dimming, regulation

I. INTRODUCTION

Objects investigated by microscopy usually can't be highlighted using reflection marks or equipped with sensors of kinematic parameters. In this case we often use advantages of image analysis and processing. Some methods for frequency measurement (using photodiode and photomultiplier) of biomechanical or microscopic objects can't do the correct analysis of structure pathologies. The most progressive method is high speed digital video method, which brings relatively good results in formation of mathematical and mechanical model of structure movement [1].

As example of moving biomechanical system we can consider cilium of respiratory epithelium cell. Each ciliated cell of respiratory epithelium contains ca. 200 cilias (6 μm long) beatings with frequency of 1000/min. Cilias are synchronized with metachronal waves propagated in periciliar liquid. From the basic position cilium folds down to the epithelium cell (recovery stroke – 75% of beating cycle) and then rapidly darts up to move mucus with its tip (effective stroke) [2].

II. DESIGN OF ACQUISITION SYSTEM

Important parameter in measurement process of biomechanical systems or moving structures is object beating frequency (OBF). In the case of respiratory epithelium this parameter has specific name: CBF (ciliary beating frequency). The value of CBF is normally in range 18-30 Hz. Image processing and FFT-based method require high-speed video acquisition system with optimal frame rate up from 400 fps [3], [4], [5].

Measurement method designed by our team is based on frequency analysis of intensity variance curve. This curve is obtained from video sequence by capturing intensity variation in selected region of interest (ROI). Curve is then analyzed with FFT algorithm, measurement is verified using curve thresholding and envelope analysis. Whole algorithm is shown in Fig. 1.

Measurement is done in graphical development system NI LabVIEW as virtual instrument and results are written as Microsoft Excel XLS file. This component helps to integrate results of investigation to laboratory or clinic information systems. Next advantage of LabVIEW virtual instrument is called Web Publishing Tool. Using this tool we can provide control of whole application through Ethernet or Internet connection.

Quality and method accuracy depends on quality of acquired video sequence and used acquisition system. The main aim of this analysis was removal of recording intensity variance curve with hardware photosensitive devices and usage of signal processing tools like autocorrelation, FFT or PSD (Power Spectral Density) for calculating object beating frequency. We can split measurement into a few solution steps, where algorithm calibration and debugging is done on phantoms:

- phantom acquisition with defined beating frequency;
- sequence preprocessing before intensity variance curve recording;
- processing of variance curve (spectral methods);
- applying on real videosequences.

To generate an accurate object beating frequency, we used DSP controlled stepping motor with reflection mark on the vane of its propeller (Fig. 2). Phantoms with defined parameters are common and useful parts in design process of new diagnostic or measuring method.

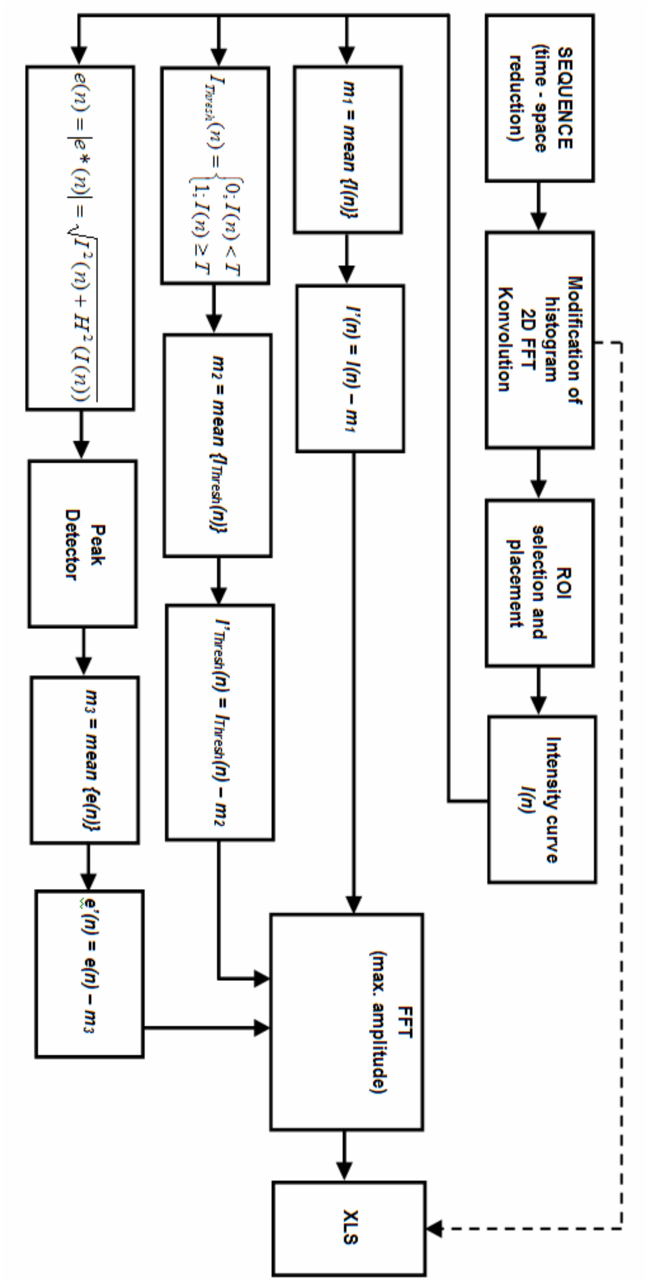


Figure 1: Frequency measurement algorithm

The first real measurements (in Clinic of pathological physiology, Jessenius Faculty of Medicine, Martin, Slovakia) were taken after algorithm debugging on phantoms. Because the ciliary beating frequency ‘in vitro’ goes down from ca. 18 Hz to a half value, primary we used acquisition system with slower camera. AVT Marlin F-046B camera was connected to inverse biological light microscope MODEL IM 1C via C-mount adaptor. Sequences from camera were stored on acquisition computer through IEEE 1394 (FireWire) as uncompressed sequences with parameters: 8 BPP / 640 x 480 pxl / 60 fps.

In the case of usage high speed camera system (Basler), microscope illumination is very important. We have changed microscope condenser light source and made some measurements of intensity by Lutron LX-1102 luxmeter.

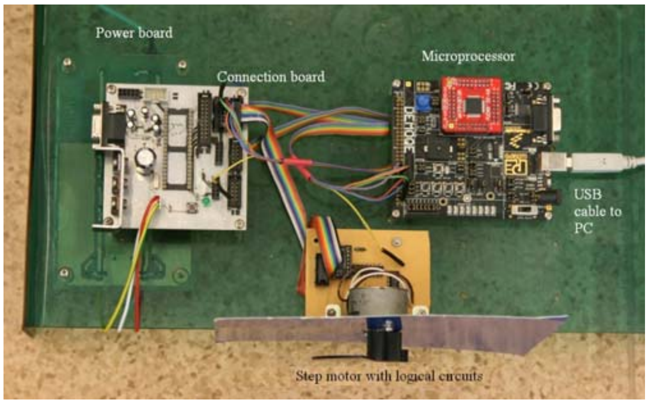


Figure 2: DSP controlled stepping motor phantom

In case of ultra high frame ratio of camera we can meet these essential problems: if the illumination of specimen is too low, frames in video sequence are underexposed and dark; if the illumination of specimen is too high, frames are overexposed and too bright (Fig. 3); high frame ratio causes growth of data for storage, so we must consider optimal connection between camera and acquisition computer.

Original maximal value of illumination (measured between condenser optics and specimen) changed from 8,6 klx to ca. 80 klx after replacing 20W halogen lamp for 120W halogen lamp. Heat from condenser must have been removed using active CPU cooler mounted onto microscope or using intelligent dimming tool.

For automatic setting of some parts of acquisition system we created regulation feedbacks controlled by LabVIEW virtual instrument (Fig. 7, Fig. 8, Fig. 9). Block diagram of mutual connections and feedbacks of whole system is in Fig. 10.

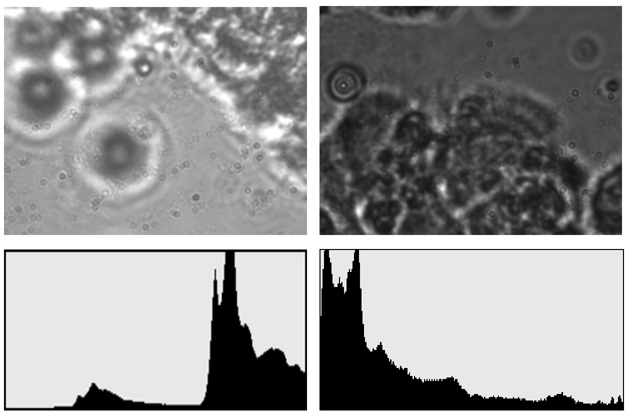


Figure 3: Overexposed (left) and underexposed (right) sequence frame and their histograms with greyscale distributions

In process of sequence acquisition, a ROI placed into image extracts important image feature: average intensity and histogram distribution. Overexposed image has its histogram concentrated to high intensity values and underexposed image to low values (Fig. 5). Histogram distribution is used as regulation parameter for setting up the PWM for halogen lamp dimmer. Lamp dimmer communicates with LabVIEW PCI card NI PCI-6221 (Fig. 11).

On the basis of simulations was designed wiring dimmer. The power supply is made directly from the mains supply 230V via input transformer. Dimming feature is provided through one PWM channel, which generates pulses at gate on switching transistor.

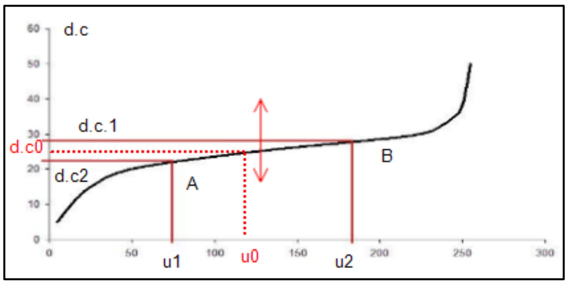


Figure 4: Image histogram mean dependence on dimmer switching pulses duty cycle

The measurement card is generating impulses to circuit. The protection and electrical separation of measurement card from the power circuit is guaranteed through the opto coupler and driver.

We can approximate the curve between points A and B (Fig. 4) as linear line:

$$y = ax + b \tag{1}$$

$$A = \lfloor \mu_1, d \cdot c_1 \rfloor;\ B = \lfloor \mu_2, d \cdot c_2 \rfloor \tag{2}$$

$$a = \frac{d \cdot c_2 - d \cdot c_1}{\mu_2 - \mu_1} \tag{3}$$

$$b = d \cdot c_1 - \frac{d \cdot c_2 - d \cdot c_1}{\mu_2 - \mu_1} \mu_1 \tag{4}$$

$$y = \frac{d \cdot c_2 - d \cdot c_1}{\mu_2 - \mu_1} x + d \cdot c_1 - \frac{d \cdot c_2 - d \cdot c_1}{\mu_2 - \mu_1} \mu_1 \tag{5}$$

$$\mu_i \langle \mu_0 \Rightarrow d \cdot c \uparrow \tag{6}$$

$$\mu_i \rangle \mu_0 \Rightarrow d \cdot c \downarrow \tag{7}$$

$$d \cdot c_i - d \cdot c_0 = \pm \Delta d \cdot c \tag{8}$$

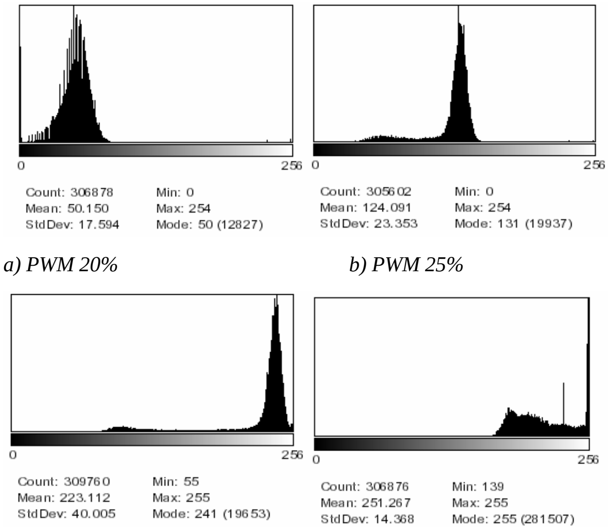
where d.c – duty cycle value
μ – gray level value

The dimmer control performance is realized through virtual instrumentation.

The proposed virtual instrumentation consist a connection of high speed video camera applications and light microscope regulatory loop. This regulation is implemented by setting the optimal switching pulse width (duty cycle). The standard frequency pulse from the measurement card is about 25 kHz to 50 kHz.

The optimal duty cycle choice is realized by the ongoing analysis of statistical parameters of the histogram of image acquisition.

The mean position of the image histogram is an important indicator of proper lighting (Fig. 5). The optimal mean value is the case in the mid-range gray level (128 at 8 bpp).



a) PWM 20% *b) PWM 25%*

c) PWM 30% *d) PWM 40%*

Figure 5: PWM image histograms

The measured characteristic is the value of the high speed video camera frame 60 fps. In this frequency was used for the halogen lamp set optimal duty cycle range 20-30% chart. The histogram mean was about 124, in duty cycle 25% and a value close to the optimum value.

While increasing the frequency is a horizontal shift towards higher value of duty cycle. Application of this regulation is using the approximation of the curve in Fig. 6.

Approximation is done with a 1% resolution of duty cycle and tries appearing mean to value near 128. For different fps is necessary to create approximations of the corresponding curves.

For halogen lamp dimming a 'switch-mode' controller circuit will be used. This type is highly efficient because very small waste of heat is generated. Nowadays there exist many different varieties depending on what type of switching system is used.

A basic Pulse-Width Modulation (PWM) switching unit suits this application. The regulator should be able to control lamp brightness from 0% to 100% (in dependency on duty cycle of the high-frequency PWM channel). Only drawback of this type of unit is the generation of high frequency 'noise' or emissions. Most of them will probably not cause any concern but they should be shielded or filtered. Another important thing is protection criterion, whereby such kind of regulator has to be fully protected against intermittent output short-circuits, input over-voltage and under-voltage conditions [6], [7], [8], [9], [10], [11].

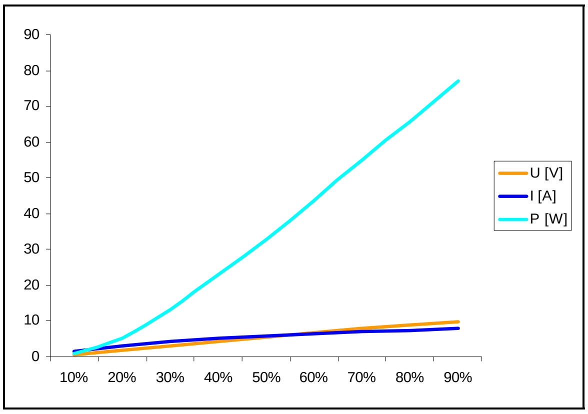


Figure 6: Dimmer output power dependencies

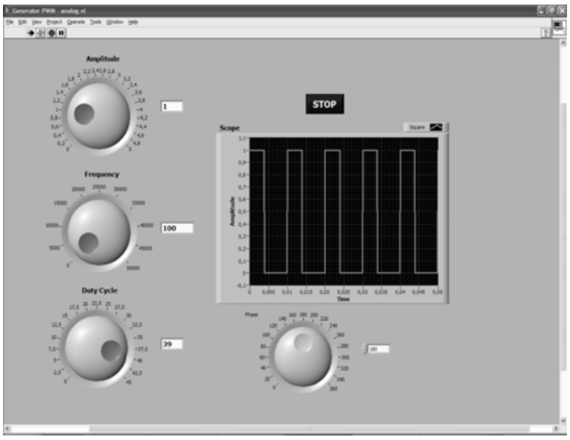


Figure 7: LabVIEW PWM regulation Front Panel for dimming application

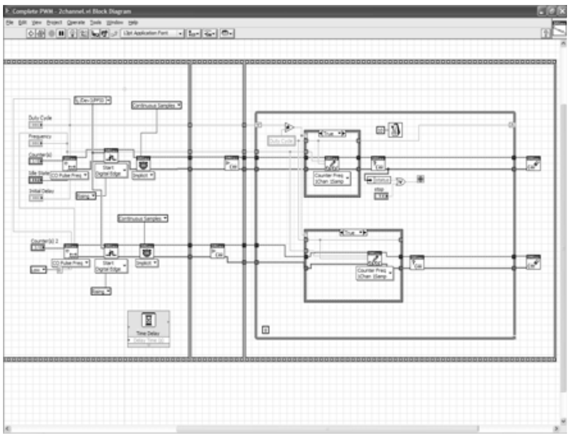


Figure 8: Part of LabVIEW Block Diagram for PWM dimming regulation & voltage / current measurements

Figure 9: FFT-based measurement Front Panel

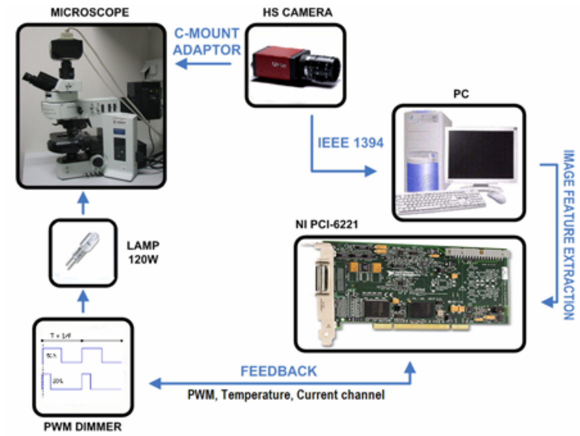


Figure 10: Scheme of acquisition system with devices, connections and feedbacks

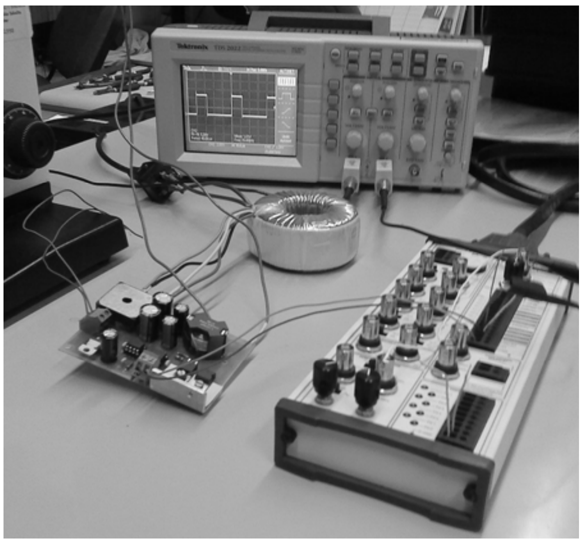


Figure 11: Testing mutual communication between microscope dimmer and LabVIEW measurement card

III. Conclusion

Designed solution for measuring object beating frequency from video sequence using tools of image analysis and spectral analysis simplifies present used methods and reduces usage of hardware devices. Using some development environment (e.g. NI LabVIEW) we can create fully automated application with interactive inputting of some parameters.

In the first approach, algorithms were tested on phantoms with defined frequency. Intensity variance curve analysis can be used in many other applications dedicated to frequency measurement not only in biological environment. Designed hardware acquisition system can be used with or without microscope in applications, where placement of kinematic parameters sensors is not able. Intelligent regulation of condenser illumination through image features extraction and histogram analysis enables fully automated approach to video sequence acquisition.

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