New Strategies for Frequency Measurement using High-Speed Video Camera System

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Abstract – **This paper describes the design, construction, and testing of a high speed cameras as a measuring sensor for position of a fast moving mechanical object. Position is evaluated by detecting the edges of the object. Datasets of these positions then becomes subject to frequency analysis aiming to determine oscillation. The functional prototype is based on virtual instrumentation making use of the LabVIEW developmental environment. The hardware part consists of a high speed video camera, PC with a camera-link frame-rabber. New method for evaluation of oscillation is suitable in range up to hundreds of hertz. The asset of suggested method is its contactless application. It can replace the most common contactless sensors.**

Keywords-frequency measurement; image edge detection; high-speed camera; virtual instrumentation; machine vision.

I. Introduction

Machine vision as a solution in measurement and testing machines has become very popular nowadays. It either replaces a human element (the element of feedback) or stands directly as a measuring sensor [1], [2], [3].

Using camera systems in industry and laboratory as part of a test and measurement system is very popular [4], [5]. It is considered to be very useful not only for trying to eliminate human factor, but also for attempting to eliminate human intervention itself while the unit is being tested. In the measurement field the camera is used for non-traditional measurement of non-electrical values [4], [5], [6]. It can be expected that prices of these systems will gradually go down thus low cost devices will get better parameters. Therefore it would be fair to say that camera solutions will be common for wide deployment in industry in the near future.

The main focus of this paper is the usage of camera sensors for measuring movements and positions of the objects. This can be successfully used for contactless measurement too. It is widely known that currently the most common tool for contactless measurement is the Doppler's vibrometer or laser triangular sensor [12], [13]. But in some situations where the vibrometer or the sensor can't be used is when the camera systems with machine vision offer a great alternative.

This paper describes a process of research of measuring relative and absolute oscillation or a mutual object's positions by the machine vision approach. The process of selecting the right components and their connections is also described.

II. Methods

Camera system can be centralized or non-centralized. The main element in a centralized camera system is a smart camera taking pictures of the scene and processing the data simultaneously. The results are then passed on further to the higher level.

Data obtained from non-centralized camera sensors are sent for evaluation to a different device. They enter a chain of a camera sensor, bus and a PC with bus interface. Due to modularity and freedom during the development the noncentralized architecture was selected. Selection of component is described next.

High speed cameras produce a higher data flow. Those cameras mostly use a camera link (CL) or a CoaXPress (CXP) bus. Data flow is in GB/s. Therefore it's very important to keep in mind the importance of appropriate bus when chosing a camera right at the beginning.

Theoretical values of speed and distance are shown in Tab. 1. For our following solution was selected a camera with camera link (CL) bus, Basler acA, price approx. 100 USD.

TABLE I. Bus Paremetrs

Bus	Speed (GB/s)	Cable Length (m)
Camera Link	0,98	10
CoaXPress	3,10	100

Due to receiving data from camera bus the PC has to contain a CL interface in form of an external plug card. This card is normally designed to plug into a PCI-Express port. The card is called a frame grabber (FG). In our case was used frame grabber NI 1433 [14].

The key feature of camera lenses is a focal length. There is no need for a lens with high focal length if the object is close enough to the camera. But if the object is further away a lens with a high focal length must be used.

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For lenses called „thin lens“ we use a simple equal model to obtain the needed focal length, Eq. 1 and Eq. 2.

$$f = \frac{1}{\frac{1}{s} + \frac{1}{s'}}. \tag{1}$$

$$\frac{x}{s} = \frac{x'}{s'}. \tag{2}$$

Where f is a focal length, x is an object from the axis of the lens, s is the height of the object, x' is the lens axis distance from the camera sensor, s' is the height of the displayed object on the camera sensor. For the next experiment was selected camera lenses with focal length of 50mm and 75mm for distances between 450 – 600 mm.

Lighting is essential component for camera system. This component can highlight what is needed to see for image process on studied object.

Lighting helps to see things clearly. Using proper object lighting reduces the complexity of mathematical algorithm is not so extensive and it doesn't required a high computing power. In Espinosa et al. (2014), Ferrer et al. (2013), Oda et al. (2011), Jeon et al. (2010), is also used light to make suitable condition. In experiments the direct and back light were used.

III. DESIGN, CONSTRUCTION AND TESTING

The idea of the experiment was to build a camera system with selected components beforehand. The next step was calibration a field of view with a specific distance with a specific camera lens. The camera was focused on a moving object while recording and evaluating the object oscillations in several different places.

As the programming instrument was used LabVIEW [10]. For support specific areas was needed programming environment add with so-called modules. For communication with the camera was used vision acquisition software (VAS) module [15] and for the image process was used the vision development module (VDM) [16].

VAS contains drivers for the most common interfaces, such as USB-vision, FireWire, Ethernet, Camera Link and CoaXPress. VDM is a wide package of software libraries for image processing.

The Pylon Viewer [17] software was used additionally for settings of the camera's parameters. The reason for the existence of special parameterized software for cameras is that there are many different manufacturers out there on the market using many different groups of parameters along with different additional pre-processing functions. Up to today universal instrument for it does not exist.

The main aim of the camera set-up is to get the highest number of images or frames per second. For a specific model of camera a acA it is 340 frames per second with a depth of 8 pixels and a full resolution 1080 x 2048. This camera uses CMOS technology where every column has its own amplifier and converter which converts electrical signal from pixels in to a digital value.

After reducing the number of pixels vertically way is needed shorter time for digitization and consequently transmission to the PC. By changing the number of pixels in one column from the original 1080 to 200 a frequency of 1700 frames per second was reached.

Another possible optimization could be conducted by allowing camera to chose only those areas of the picture which are needed for the process. In that case it wouldn't be necessary to digitalise the whole picture and it would be possible to increase the frame rate as well. Unfortunately this option is not available yet.

However the frame rate increase introduces a problem of necessity to decrease an exposure time. This results in a lightsensitive layer of pixel getting less light. In order to increase the amount of light a lens with lower aperture number must be used as well as a camera with physically higher pixels size which can become quite expensive though. The easiest solution is to illuminate a particular area of the picture to highlight the object's contours. During experiment was used a direct light and a back light.

VDM in LabVIEW provide tools to work with image correction and calculating the distance in real values. For any measurement starts the camera and it's view has to be calibrated. This is done with a pre-defined grid of points.

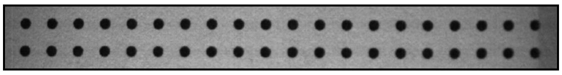

Figure 1. Calibration grid snap by camera

After capturing the grid of points the thresholding takes place. In practice we use two types of thresholding; global and local.

The global thresholding method compares all pixel values in the image with a single value. Calculating of this value is normally based on the histogram of the entire image. This method is suitable for use with the uniformly lighted scene.

The local thresholding method uses a different value for every pixel. It is computed from the intensity values of its surrounding pixels. The threshold algorithm is used for grid Eq. 3 [18].

$$T = m + k \times \sigma. \tag{3}$$

where T is the threshold value, m is mean value, k is constant design by Niblack (1986) on value -0,2 and σ is standard deviation. Algorithm Eq. 3, brings binary noise for empty mask, from that is computing threshold value, Feng and Tan (2004). This noise was eliminated erosion and dilatation of binary image.

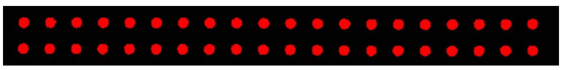

Figure 2. Calibration grid after threshold and filtration

Center of all points in binary image on Fig. 2 are used for computing radial and prespective distortion.

This calibration information is stored in the picture as metadata. Data obtained from the picture are then used for calculating of the found coordinates on the actual image, like in Oda et al. (2011).

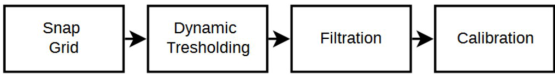

Figure 3. Steps of calibration – for measurement in real units

For the evaluation position of any object there are several different areas with different positions chosen. To mark each of these positions we use a Region Of Interest (ROI). ROI is a rectangular area defined by two points in the picture. Each of these areas, ROI, is evaluated separately and parallelly to ease the calculating process. It is similarly done in Ferrer et al. (2013); Espinosa et al. (2014); Jeon et al. (2010).

In ROI the position of the object is represented by the position of edges. That is the fastest solution, as it's not necessary to track the whole object during the process. It is again done the same way in Jeon et al. (2010); Oda et al. (2011).

The found location of the edge is for the purpose of evaluation stored in the additional FIFO memory in order to collect a sufficient amount of information. After gathering the sufficient amount of data the “Fast Fourier Transform” (FFT) – representing frequency analysis - is computed. Subsequently to that the oldest value of the FIFO memory is deleted and a new information is added and again the FFT is computed again. The cycle like this runs parallelly for each ROI.

The entire application was implemented in LabVIEW language. LabVIEW enviroment contains full-fledged tools for programming application in automatization, measurement and testing areas.

The application is written/runs in two independent processes, Grabbing and Computing, see Fig. 4. The reason for using this architecture is that the Grabbing process is timed by a camera and not receiving a picture would lead into an error.

These two processes have to be synchronised and therefore the queue of images is used as a synchronising tool. The Grabbing process communicates with the camera and grabs the images which are passed further in to the queue of images. These images are then taken and processed by the Computing process.

Figure 4. Application runs in 2 independent processes synchronised with queue of images

The calculation process takes images from the queue, see Fig. 5. The extraction of the picture is made based on the pre - selected ROIs. According to the number of ROIs the following operations are executed into a separated threads: edge localization → re-calculating the coordinates into a metric system based on the previous calibration → buffering data – FIFO storage → computing FFT.

After all these steps the results are passed onto a user interface.

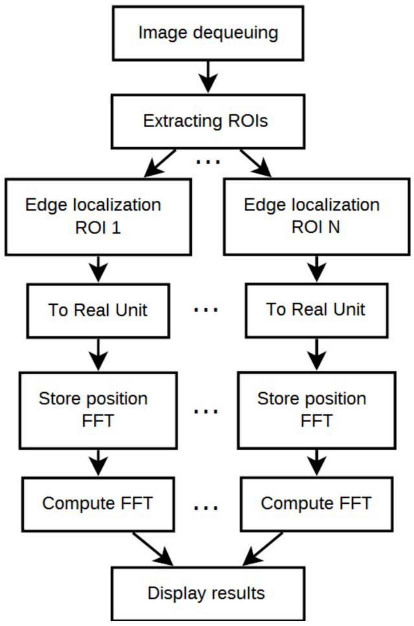

Figure 5. Code Blocks in computing process

IV. Results

For the testing purposes were used a bass speaker and a guitar, see Fig. 6 and Fig. 7.

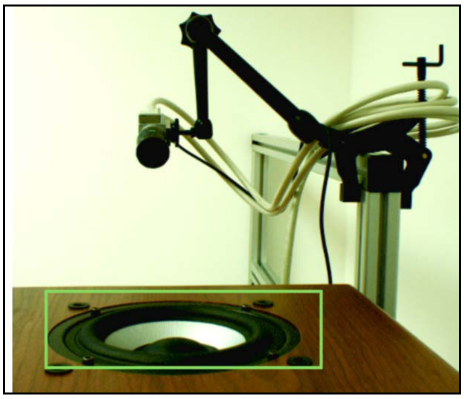

Figure 6. Speaker measurement

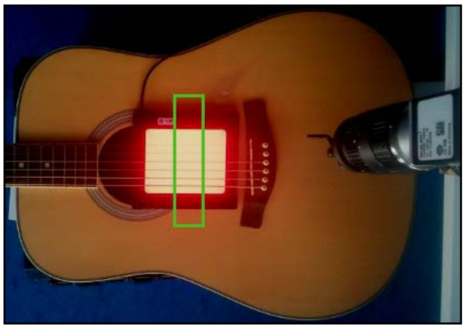

Figure 7. Guitar measurement

There was a membrane track on speaker. The distance between the camera lens and the speaker was 600 mm. On the Fig. 8 we see the camera view of the speaker membrane. It's a side view. The green rectangle represents the selected ROI. The red dots represent the location of the found edge

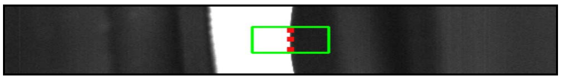

Figure 8. Testing on speaker

The speaker was driven by a sinusoidal signal from the low frequency generator. While keeping the constant distance between the camera and the guitar, the frequency range was constantly being evaluated. The oscillations frequency evaluated by this application was equal to the generator's frequency.

In the range above 400 Hz the measured signal was lost in noise. This was caused by the drop of the speaker membrane's yaw and by the frequency increase. This way the camera's resolution for the distance between camera – object becomes insufficient. The solution would be to bring the camera closer to the object. The measured results are shown on the Fig. 9.

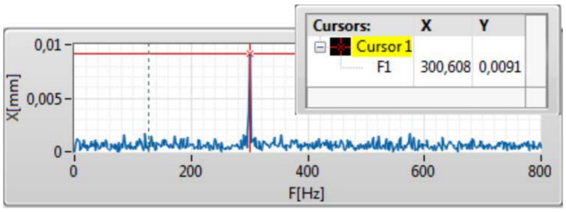

Figure 9. Measured frequency of speaker

The capturing frequency was 1700 frames per second (fps). According to the sampling theorem it is known that the maximum measurable frequency is 850 Hz. Any higher frequency appears after FFT calculations in a range from 0 to 850 Hz as an “alias frequency”. We wouldn't get true resultsfor the signal above 850 Hz.

For example a frequency of 1900 Hz appears in the measured range on frequency (absolute value of subtract: the closed integer of multiple sample rate minus frequency of measuring):

- |1700 – 1900| = 200 Hz.

It is a normal practice to include the antialiasing filter before the AD converter, e.g. when working with an accelerometer. But by camera measurement it is no possible.

The frequency measurement accuracy is determined by the number of FFT calculated positions. Generally for calculating of steps between two discreet values of frequencies in the spectrum the following Eq. 4 is applied.

$$\Delta_F = \frac{F_s}{N} \qquad (4)$$

Eg. 4 using a frequency of 1700 Hz with 2048 samples for FFT gives us the following: 1700/2048 = 0.83 Hz. The change of samples for FFT affect time window of FFT.

There was another experiment conducted on guitar strings. This experiment demonstrates a measurement parallelism. The following conditions had to be met:

- the distance between the camera and the guitar strings had to be 450mm,
- back light which had proved itself as the most useful (using a direct light caused reflection of the strings),
- string movement was started manually.

The measurement's steps are the same as the ones mentioned before. The first step was the calibration according to the point 3.4 and then the measuring itself. The Fig. 10 shows the camera's view. The green rectangles represent/show 6 ROIs chosen by the user above each string.

The Fig. 11 shows the string detail where the yellow dots represent the found string's contour.

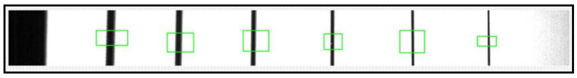

Figure 10. Testing on guitar strings

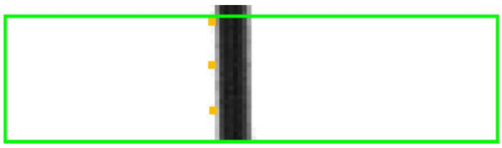

Figure 11. Displayed edge in image – Detail on strings

The Fig. 12 shows the results of measuring the frequency on strings. Here are valid the same assumptions as with the speaker's experiment. Different ROIs on Fig. 12, are distinguished by different colors according to the string.

We can see that apart from the base frequencies of the tone their harmonic frequencies stand out as well. Size of these harmonic frequencies make a color of the tone. This feature was possible to measure only in a short time right after a strong intervention. After that these frequencies can't be measured any more as the camera resolution is not enough to detect them anymore.

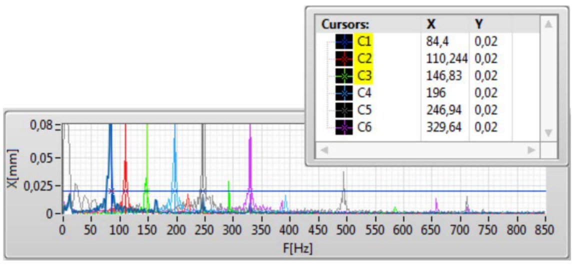

Figure 12. Measured frequency spectrum of strings

The Fig. 13 shows the results of measuring the frequency on the string e1.

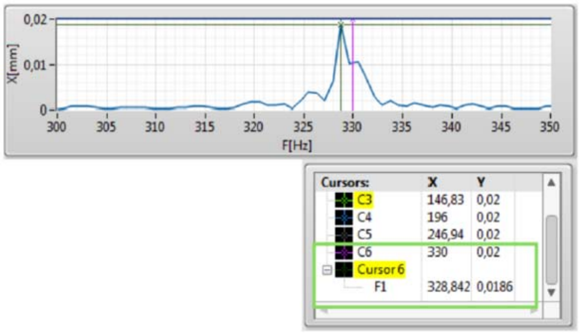

Figure 13. Frequency analyze of string e1.

V. DISCUSSION

From experiment follows that, by measuring oscillation in range of tens of hertz is possible to use low-cost cameras, like in Oda et al. (2011), but on the other hand in range of hundreds of hertz a high speed cameras are needed. Using a row camera can be reliable detected oscillation in ones of kilohertz. Row cameras has a frame rate up to tens of kilohertz and also has higher resolution then any area scan cameras.

In order to increase the sensitivity of existing method will by asset to use sub-pixel accuracy method for finding position of edge, like Espinosa et al. (2014); Mas et al. (2014). In terms of computing power it will be good step to be realized a part of algorithm on graphical processing unit. This issue will be investigated in the future work.

VI. CONCLUSIONS

Suggested method for evaluation of oscillation is suitable in range up to hundreds of hertz.

The asset of suggested method is its contactless application. It can replace the most common contactless sensors that is not possible to use due to some condition. Measuring range and accuracy is affected by camera type and properties of camera lens as well.

In described case it was high speed camera where was reached measurement range up to 850 Hz with sensitivity 0.01 mm, in 500 mm distance from object. In order to increase frame rate of camera was limited vertical size of image on 200 pixels. Measurement in metric units was done by perspective a radial calibration field of view.

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