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Development of vibration measurement and processing methods using line scan cameras

PhD thesis booklet

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I. GOALS OF THE DISSERTATION

In industrial applications using contact vibration measurement method is often not possible, therefore contactless methods has more and more importance. This is one of the reasons why laser distance sensors are widely used for vibration measurement, although the sampling rate of these sensors is still lower than the speed of the industrial contact vibration sensors. In order to increase the performance of contactless measurement, development of new methods is required. One of the possibilities is to use line scan cameras, as its resolution and speed enable the application for high-speed vibration measurement.

II. SCIENTIFIC BACKGROUND OF THE RESEARCH

In the fields of optical measurement techniques the main disadvantage of the area scan cameras applications is their low speed. Nowadays high-speed digital cameras are available, suitable for taking 100 000 pictures/second. Nevertheless this speed can be reached only in case of extremely small resolution sensors containing ~128x64 pixels which is not enough for most measurement applications. Increasing the resolution of sensor the obtainable speed is decreasing. For example in case of a sensor containing 640x480 pixels the speed is only 36 000 fps (frame per second). The other great problem is the amount of data. The high-speed cameras even in case of small sensor size produce huge amount of data, online transmission of them to the computer is impossible. This is the reason why the time of the continuous (no interruption) record of these cameras depends on the capacity of their caches (integrated memory inside of the sensor). In practice most of the high-speed cameras are capable of taking pictures continuously for 5-7 seconds.

In my opinion the area scan cameras can not race with the widely used laser distance meters because of their resolution and speed.

In line scan cameras the sensor contains only one pixel line with 2 048, 4 096, 6 144, 8 192 pixels in general, but nowadays models with 24 576 pixels are also available. In spite of the high resolution these cameras are able to take even 80 000 pictures/second. From the measurement technique's point of view this is equivalent to the sampling frequency. On the basis of these two features I decided to examine the practical applicability of these cameras in the field of contactless vibration measurement. Traditional application of line scan cameras is growing in the industry but in area of the measurement it is not significant. Studying relevant scientific references there are two including the most sophisticated solutions in this area.

The first one *Visual measurement of pile movements for the foundation work using a high-speed line-scan camera* is published in 2008 in *Elsevier, Pattern Recognition* journal (further it signs Lim&Lim). Authors have developed a simple pattern containing black and white areas. Fitted this pattern to the steel pile the authors can measure the vibrations and movements of the pile by 10 kHz sampling rate. They used finite sample measurement method for 10 seconds. Accuracy of the measurement was about 120 μm.

The second publication *Seismic structural displacement measurement using a high-speed line-scan camera: experimental validation* was published in 2010. In this article the authors implemented the simulation of the measurement of seismic events using the pattern and measurement method of Lim&Lim. The used resolution is about 30 μm. This task does not need high sampling frequency therefore the line scan camera was used with only 1 kHz. The relative error of the tests was less then 3%.

In industrial environment we usually have to perform measurement in special circumstances making impossible the use of traditional, widely used methods. My goal is to develop a sensor suitable for industrial applications with comparable to the laser distance sensor's quality properties, that is efficient in economical and also in technical meanings, e.g. the measuring rate can be set in wide range.

III. NEW SCIENTIFIC ACHIEVEMENTS, UTILIZATION OF THE NEW SCIENTIFIC RESULTS

Summary of the new scientific achievements

One of my goals was to develop a simultaneous multidimensional measurement method for movement sensing. In my opinion it is possible only in case of using a fitted pattern on the surface of the measured object. Therefore my research area was narrowed to pattern based measurement methods. The theory of the measurement method is shown in the figure 1.

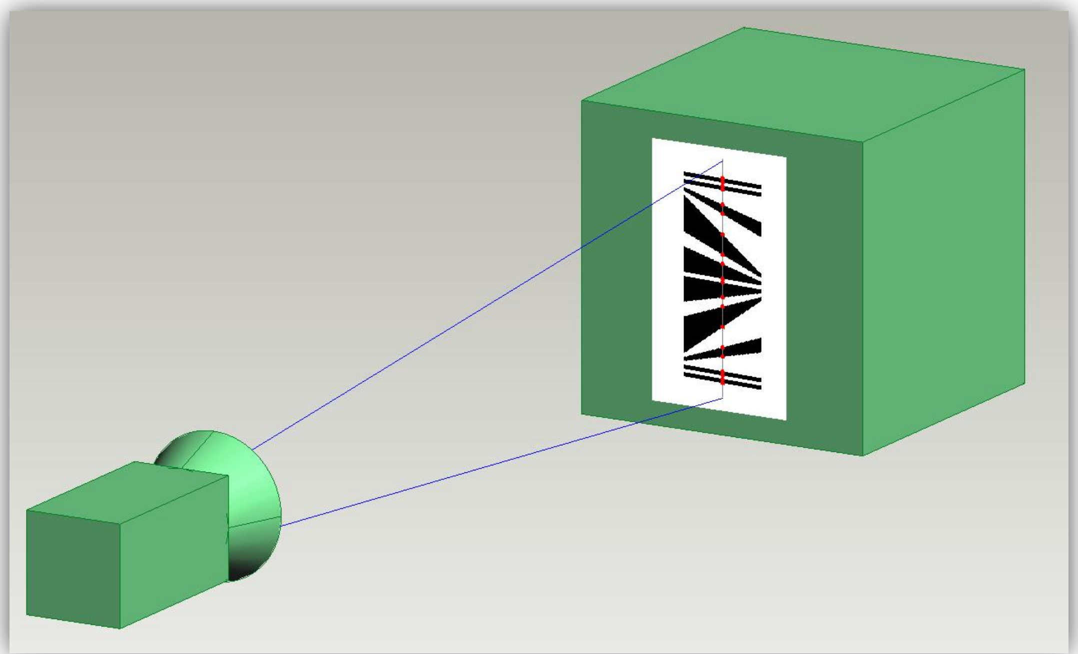

Fig. 1
Demonstrating the theory of measurement

Determination of all transformation parameters is not possible using only one pixel line. But nowadays we can build special measurement cameras with two line scan module. The figure 2 demonstrates this measurement method.

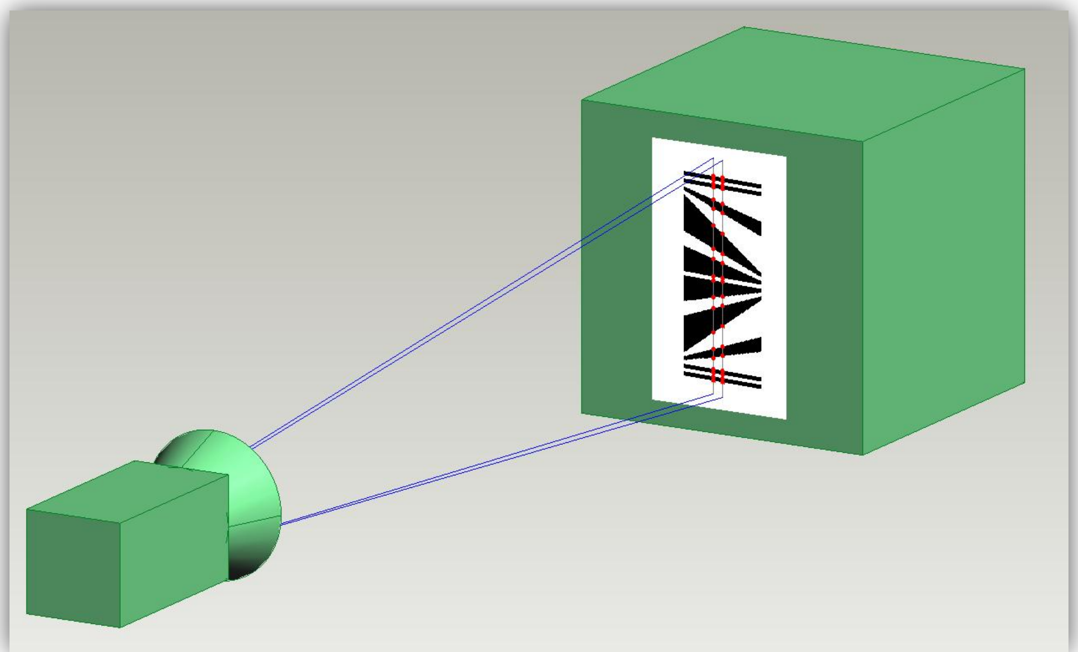

Fig 2.
Demonstration of the two lines measurement method

For these measurement methods I need a specially designed pattern attached to the measured surface, therefore I have developed a sizeable pattern. It is shown in the figure 3 with different size parameters.

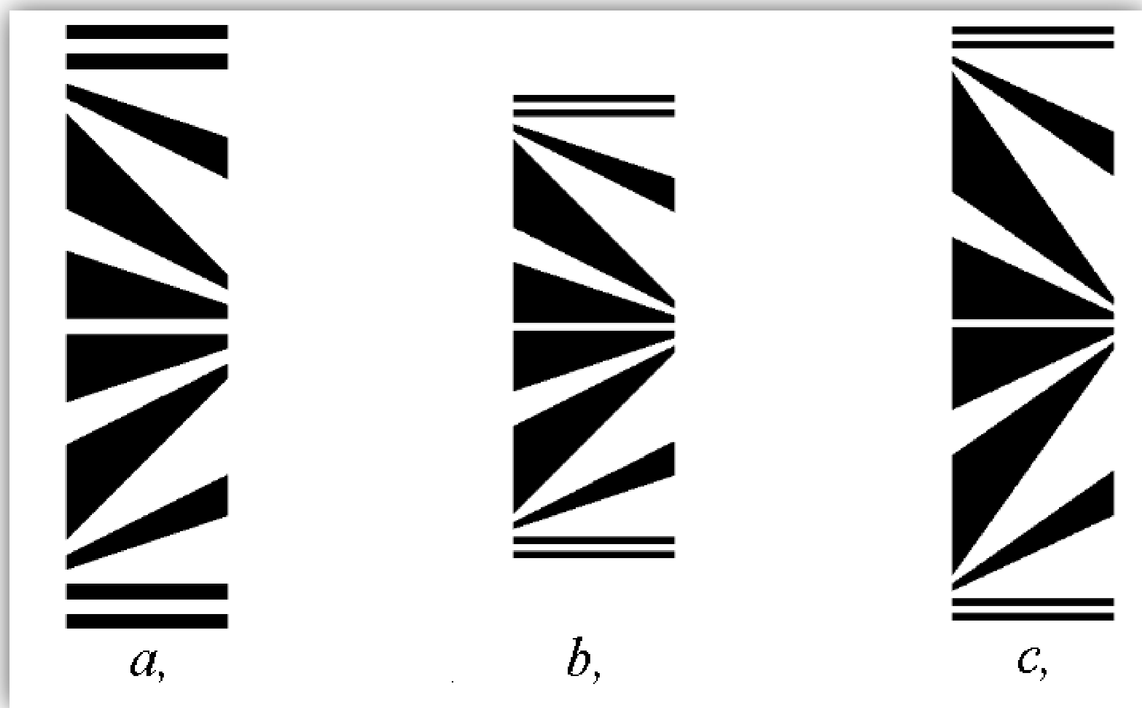

Fig 3.
Final pattern with different size parameters
a: (z) 1 mm, (C_{max}) 1, b: z=0,5 mm, C_{max}=1; c: z=0,5 mm, C_{max}=1,5

***Thesis 1**: I have developed a special pattern containing black and white areas which should be fitted to the surface to be measured. The method using line scan sensors for recording movement of this pattern is suitable for simultaneous determination of multidimensional movements of the object.*

The developed pattern is not a universal and general one which can be just simply printed and fitted, but it should be resized and optimized to the actual measuring task. In order to make the resizing process possible and user friendly, I have developed a pattern sizing method.

***Thesis 2**: I have developed a new method for sizing the pattern described in thesis 1. in order to make it suitable for application specific definition. This method is suitable for dynamical changing of the pattern's sizing parameters considering expected ranges and resolutions of each dimension.*

Results of the measurement are the actual measures of the movement in length and phase. To get these real results from the lines measured by camera we need special conversion algorithms using effective mathematical model. In my thesis I have developed the mathematical model suitable for specification of the pattern shape and the effects of the three dimension transformations.

Thesis 3*: I have developed a mathematical model for simplified algorithms used for the effective computerised processing of data provided by one and more lines sensors. Functioning of the mathematically deduced and developed model was analysed in details and its pertinence and operation was verified by my simulation and testing application.*

After the verification of the deduced mathematical model I have developed the measurement methods and their processing algorithms for the simplified model. This model doesn't take into consideration the effects of the perspective deformations. Pertinence of the developed algorithms I verified with my simulations and testing application.

Thesis 4*: I have developed measurement methods and processing algorithms using one or two pixel rows suitable for determination of axial movements and rotations of a surface performing free movement within a defined measurement range. Using one pixel row one axial movement and rotation can be determined. Using two pixel rows two axial movements and three rotations can be determined.*

The data processing time is a very important parameter of the processing algorithms, it defines the practical applicability of the theory. With my two pixel rows measurement method and my data reduction method data received even from high performance line scan cameras can be effectively processed making possible the continuous measurement.

Thesis 5*: Using method and algorithm described in thesis 4, for two pixel rows I have developed an online contactless vibration measurement method suitable for online detection and processing of two axial movements and three axial rotations of a free-moving surface measured by high sampling frequency.*

Utilization of the new scientific results

We can use the developed measurement methods and processing algorithms in their actual form if the perspective effects are negligible in the measurement circumstances.

The big data is a heavy problem in the area of the camera measurement methods. I solved this problem in my pattern based tasks with a specially developed data reduction, which can be also applied and further developed for other measuring methods and for use in big data analysis.

In this thesis project I aimed to develop my pattern to flat surfaces. But we can modify this pattern also to rotation rods. The three dimensional vibrating measurement of the rod will implement with this modified pattern.

In the future I would like to test the two pixel lines measurement method in the practice too. For this I have to realize a special line scan camera with two separated pixel rows.

My data reduction unit was developed to a more expensive FPGA measurement card. In the future I would like to implement it without special measurement card.

IV. MAIN PULICATIONS

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