CORRECTNESS OF VELOCITY EVALUATION OF SYSTEM USING SPATIAL FILTER

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Abstract

In this paper, a velocity measurement method using the spatial filter is presented. Luminous emitance of the surface passing through the moving spatial filter and optical set is projected to the active area of photo-detector. The velocity determination is based on the frequency spectrum evaluation of the photo-detector output signal. The formula for velocity computing is derived first. Then, correctness of velocity evaluation in dependence on the surface and measuring system properties is discussed.

Keywords

Velocity measurement, spatial filter, photo-detector

1. Introduction

The measurement system, described in [1] and [2], is depicted in Fig. 1. The photo-detector with an optical set and a filter moves at a constant velocity v_x in a direction perpendicular to the stripes of the filter. As presented in [2], photo-detector generates a voltage $u(x)$ proportional to the convolution of the filter impulse response $D(x)$ of the length L (see Fig. 2) and the luminance of the texture $B(x)$

$$u(x) = u(v_x t) \approx \int_0^L B(\xi) D(x-\xi) d\xi \cdot \qquad (1)$$

The rate of the detector output voltage variation depends on instantaneous velocity v_x of measuring system movement. The principle of the velocity evaluation is depicted in Fig. 3. To put the facts in a simpler way, the luminance of the background texture $B(x)$ was chosen in the form of a single luminous point on a dark background. Projecting this point through spatial filter, periodical function of voltage $u(x)$ is achieved in accordance to (1). In the spectrum $U(k)$, the first and the third harmonic spectral components appear then. The non-transparent area of the impulse characteristics $D(x)$ corresponds to the level 0, while the transparent equals to the level 1. The result of the convolution $u(v_x n)$ is depicted with relation to the discrete time nT_s (T_s=1). For the spectrum computing, the 1024-point FFT with Hanning window was used.

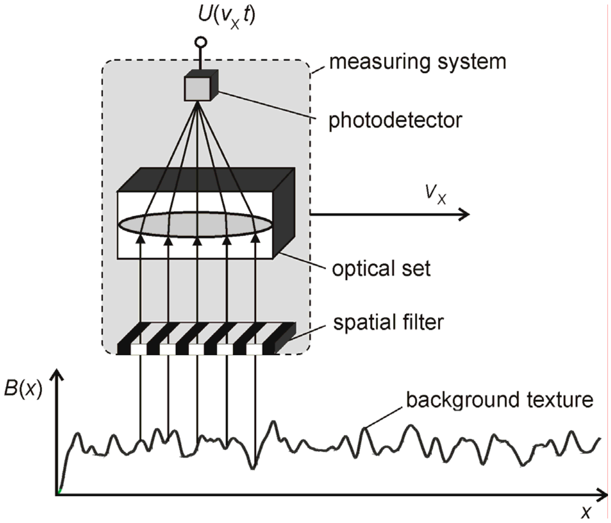

Fig. 1 Principle of the measurement exploiting the spatial filter

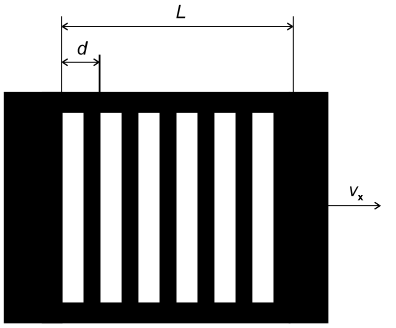

Fig. 2 Structure of the spatial filter

2. Correctness of Velocity Evaluation

For the purpose of a real application simulation, the texture luminance was generated by the function *rand* in Matlab. In order to eliminate too rapid changes, numeric filtering by the third-order Butterworth filter was used. (see Fig. 4 and Fig. 5).

The process of velocity evaluation is simple. After the transformation of the signal $u(x)$ into the frequency domain using the N-point FTT, we can find the elementary harmonic component corresponding to the requested velocity, which is dominant if the length L of the filter has been chosen correctly. Its position in the spectrum, marked with the symbol k, corresponds (under the condition of a known sampling period T_s and the width of the spatial filter period d) to the velocity of the movement since $1/NT_s$ is the distance of two neighboring lines in the spectrum $U(k)$, and NT_s/k is the time in which the filter moves of a value d at a velocity v_x which may be written in the form

$$v_x = \frac{kd}{NT_S}, \quad k=1,2,\ldots,N/2. \tag{2}$$

For a particular application, we have to choose convenient parameters d, N and T_s. The impact of the length L of the filter on the magnitude of searched spectral components compared with the magnitude of other components is shown in Fig. 4 ($L = 4d$) and Fig. 5 ($L = 16d$). In both cases, the maximal magnitude should have a coefficient $U(16)$. Obviously, this is not true for the first instance. On the basis of many experiments, we can state that $L = 16$ ($N = 1024$) is sufficient for spectrum computing, when the component magnitude corresponding to the real velocity is dominant in all measurements. A critical parameter of velocity evaluating is the sampling period T_s. Its value should be chosen with regard to the length of the filter period d. Always, the sampling condition

$$T_S \le d/2v_{x\,max} \tag{3}$$

has to be fulfilled since the maximal velocity $v_{x\,max}$ causes the voltage $u(v)$ to contain a component of the frequency $f_m = v_{x\,max} / d$. Besides, even higher harmonic components appear in the spectrum of this voltage (see Fig. 3). Their existence above the frequency f_m can be eliminated by the use of the anti-aliasing filter. If these harmonic components appear below the frequency f_m, they do not influence the measurement significantly, since their magnitude (compared with the basic harmonic component magnitude) is significantly lower ($|U(3)| = |U(1)| / 3$, etc.). Another possible way to achieve more expressive elimination of higher harmonic components consists in using a spatial filter with harmonic impulse response. Its realization is more complicated, and its use probably does not bring any marked effect. The sampling period T_s has to meet another criterion, which is the time of one measurement T_m. If the system is to analyze the instantaneous velocity, the time of the measurement has to be short related to the allowed time change of the measured velocity (i.e., to the acceleration). This problem deserves a more detailed analysis.

In this paper, the velocity change within one measurement period is supposed not to exceed the system resolution Δv, which is given by the following formula

$$\Delta v = 2v_{x\,max}/N\,. \tag{4}$$

Supposing the voltage $u(x)$ to be sampled first and the samples to be subsequently processed then, the total measurement time is given by the relation

$$T_m = NT_s + T_v,$$

where T_v is the time needed for the samples processing. When suggesting a system for processing the samples, certain lacks in the method should be also respected. The first one appears in the case of a constant texture. Then, the voltage is also constant, and only a coefficient corresponding to the DC voltage component appears in its spectrum.

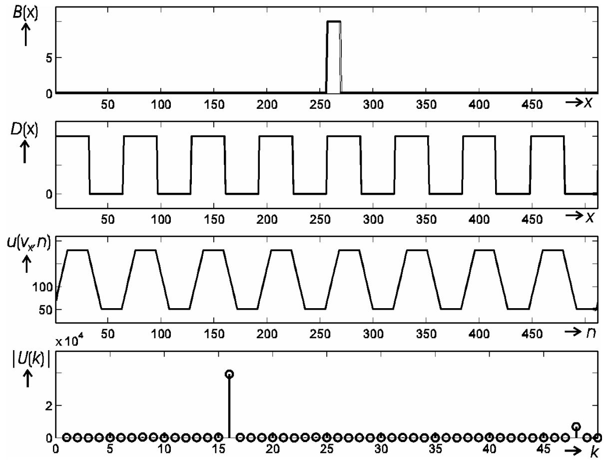

Fig. 3 Demonstration of the velocity evaluation when using the simplest case of the texture luminance $B(x)$ - single luminous point on a dark background.

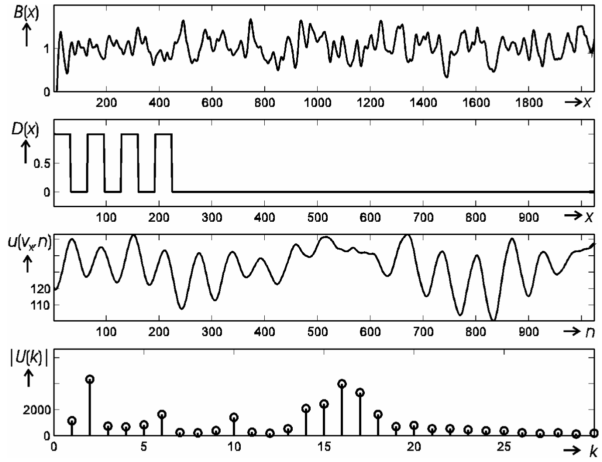

Fig. 4 An example of computing the spectrum $U(k)$ for $L = 4d$.

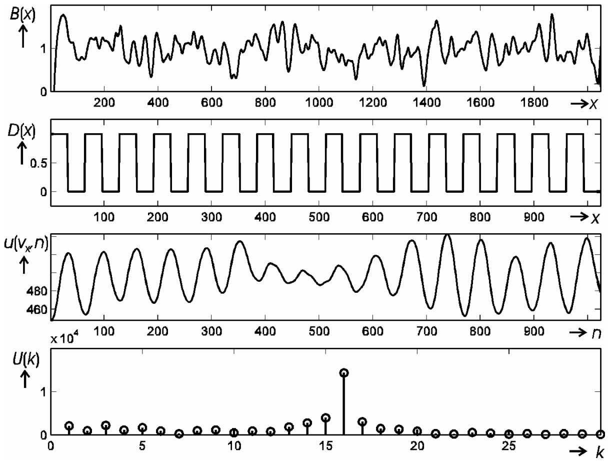

Fig. 5 An example of computing the spectrum $U(k)$ for $L = 16d$.

As mentioned in [3], similar problem may appear even in the case of a periodic texture with the period D. Assuming $nD = md_p$, where $n = 1, 2, 3,\dots$, m is an arbitrary integer divider of the ratio L/d, and d_p is the width of the transparent filter stripe (the most frequent case is probably $d_p = d/2$), a constant voltage appears at the output of the photo-detector. If the above-presented conditions are not fulfilled, $u(x)$ becomes a periodical function containing coefficients corresponding to the frequency of $1/d$ in the spectrum only, the frequency corresponding to the movement velocity is absent there. The situation is depicted in Fig. 6 and Fig. 7. In both cases, the magnitude of the coefficient $U(16)$ is again dominant. The presented method of measurement should therefore be applicable to the cases when luminance of the texture shows a non-periodic random character.

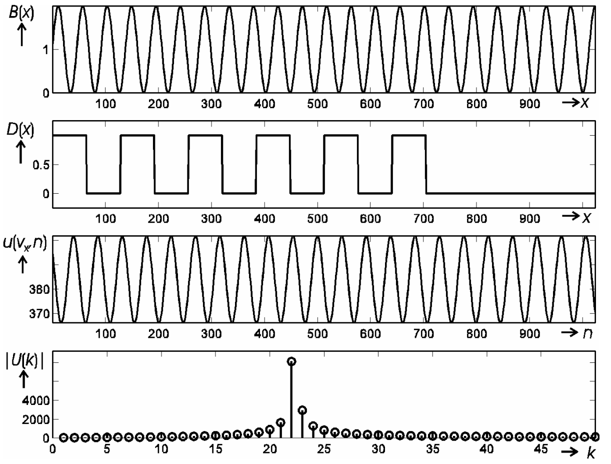

Fig. 6 An example of the velocity evaluation when a periodic harmonic texture are used assuming $D < d$ and $nD = md_p$.

3. Conclusion

In this work, the influences of the fundamental system parameters on correctness of the velocity evaluation were simulated. By means of acquired results a number of rules and relations, which are needed for practical system design, were introduced.

The described method was implemented using Motorola digital signal processor DSP56002 which performs a number of operations: $u(x)$ filtering, FFT computing, maximum-amplitude coefficient locating, velocity computing (according to eqn. 2), and finally, result display. In the following step, processes for better spectrum processing (additional filtration, computing averages of several measurements, etc.) are going to be looked for.

Below, we give a simple example of the measuring system design. The given values are: $v_{x\ max} = 180$ km/h (50 m/s), $N = 1024$, $v/T_m = 5\text{m/s}^2$. Next, we suppose to hold $T_v = 8$ ms for the exploited signal processor. Then: $\Delta v = 2\, v_{x\ max}/N = 0.35$ km/h (0.097 m/s), $T_m = 19.4$ ms, $T_s = (T_m - T_v)/N = 1.1\cdot10^{-5}$ ($f_s = 90$ kHz), $d = 2\, v_{x\,max} T_s = 1.1$ mm. Computing FTT, the movement velocity v_x is given by (2).

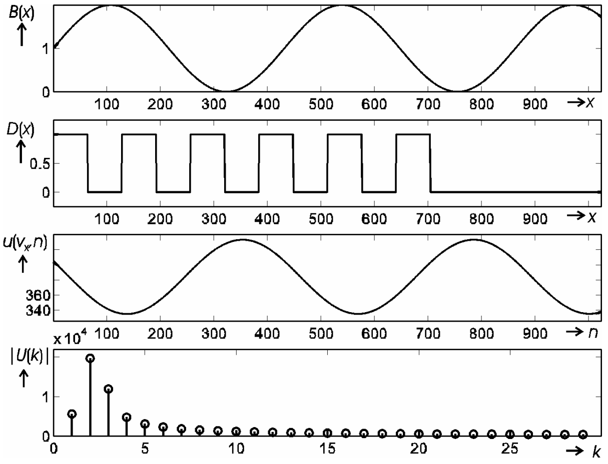

Fig. 7 An example of the velocity evaluation when periodic harmonious texture was used assuming $D > d$ and $nD = md_p$.

Acknowledgement

This work was supported by the Grant Agency of the Czech Rep., grant project No. 102/00/0043: *Research and Applications of Optoelectronic Methods in Measurement and Communications, Medical Diagnostic and Environmental Engineering.*

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Aleš PROKEŠ was born in Znojmo in 1963. He received M.Sc. and Ph.D. degree from the Brno University of Technology in 1988 and 2000, respectively. Currently, he is assistant professor at Dept. of Radio Electronics, BUT. His research interests include signal processing and optical communication.