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AN IMAGE PROCESSING MEASUREMENT ON SPATIAL FREQUENCY DOMAIN

Prof. Tsunehiko Nakanishi and *Ass. Prof. Kozo Taguchi*

Faculty of Science and Engineering, RITSUMEIKAN University
Shiga, Japan

Abstract – A measurement system of vehicle speed using video camera and its brightness analysis is proposed on this paper. The blur is paid attention above all. Since a blur on an image can be measured by the frequency analysis, the possibility to measure speed of a moving object by using a blur image is considered. However because of partial brightness noise, the object length components are included other than the blur component in the information of moving speed, the some filters are introduced on the brightness domain and frequency domain to eliminate unnecessary components. It was possible to separate clearly between speed component and unnecessary length components, and the possibility to measure speed can be found.

Keywords: spatial frequency, image processing, non-contact measurement

1. INTRODUCTION

An image processing measurement method is employed on the industrial site to measure or observe something of moving objects as non-contact measurement method. So the object shape appears as the brightness distribution on a video picture plane, the recognition and/or measurement of an object are not so difficult in case of the simple object shape and the good background condition. These conditions are unusual case and most of measurement condition is not adequate to measurement. The some filters should be employed to eliminate noise or background information on the usual measurements in pursuit of reduction of measurement errors. These filters are consisted on direct domain as spatial length on the video picture plain. Though the construction of length domain filters is simple on the ordinal case, the direct domain method is not sufficient in some case especially it contains not so small background noise.

As the information of measuring objects has many projective spaces, an appropriate projective space should be chosen at the measurement concerning to noise reduction or accurate measurement. The measurement becomes easier by the employing another signal domain rather than analyze on the direct signal domain as the brightness distribution for image processing measurement. The brightness distribution on spatial length domain of a video picture plane is one of the projective spaces of the measurement object and the spatial frequency spectrum of brightness distribution is also a projective space of the object [1]. One of the frequency domain methods to measure object movement using image processing method is shown in this report.

It is very important to make clear the mapping relation of characteristics of an object between both domain to develop the appropriate filters, and it becomes possible to design the appropriate filters by the definition of mapping relation. An appropriate projective space and noise elimination filters should be employed in the practical measurement as same as usual measurement. The spatial frequency spectrum made by Fourier transformation is the projective space of a measurement object. Though this transformation is useful to select up the required information from lot of unnecessary information or noises, it is not enough to eliminate another noises such as brightness noises or shadows. It is useful to combine another domain filters like as spatial frequency domain for signal treatment from background noise.

The possibility of practical use of combination filters on both domains is reported to measure vehicle shape and vehicle speed which are requested on automobile traffic flow analysis on this report. The traffic flow measurement was difficult using usual simple image processing measurement method because the background condition of vehicle flow on a practical road is poor surroundings for the measurement as outdoor measurement and variety of vehicle shape or colours.

2. SPATIAL FREQUENCY SPECTRUM OF A MOVING OBJECT

The brightness distribution $g(x)$ on an arbitrary line of video plane for the moving object which brightness distribution is explained $s(x)$ at static state is shown as,

$$g(x) = \frac{1}{T}\int_{-T/2}^{+T/2} s(x - vt)dt \quad (1)$$

where v is moving speed on x axis direction and T is exposure time on an imaging plate, and the frequency spectrum $G(f)$ of $g(x)$ is show as,

$$G(f)=\int g(x)e^{-2j\pi fx}dx$$
$$=\left(\frac{1}{T}\int_{-T/2}^{+T/2}e^{-j2\pi fvt}dt\right)\left(\int s(x)e^{-j2\pi fx}dx\right) \quad (2)$$

and power spectrum envelope of spatial frequency $P(f)$ is derived as,

$$P(f)=\frac{\sin^2(\pi vTf)}{(\pi vTf)^2}\cdot S^2(f) \quad (3)$$

as the function of spatial frequency f. If the integration range differs from as (1), the phase term in (3) is diminished by the derivation of power spectrum. This spectrum has two components which are speed component v and frequency spectrum $S(f)$ of object shape. The first term which corresponds to speed component is called as the blur effect, and this term is undesirable effect for an usual picture at slow exposure time. But this term is useful to measure moving speed. There is periodic characteristics on the frequency domain concerning to moving speed though it contains hyperbolic component.

For example, the power spectrum $P(f)$ for a $s(x)$ of simple rectangular function become as,

$$P(f)=\frac{\sin^2(\pi vTf)}{(\pi vTf)}\cdot\left\{\frac{H}{\pi f}\sin(\pi Lf)\right\}^2$$
$$=\left\{\frac{H}{(2\pi^2 vTf^2)}\right\}^2\{1-\cos(2\pi vTf) \quad (4)$$
$$-\cos(2\pi Lf)+\frac{1}{2}\cos 2\pi(L\pm vT)\}$$

where L is object length and H is object brightness. The second term in the brackets is a speed component, third is a length component and fourth are sidebands of length with speed components.

Fig. 1 shows an example of periodic feature on the power spectrum $P(f)$ for $L=5\text{m}$, $v=20\text{m/s}$, $T=0.05\text{sec}$. The two periodic components appear clearly in the figure, the long period appears in each 1 cycle/meter and short appears in each 0.2 cycle/meter. The long period corresponds to the product of speed and imaging time, and the short period corresponds to object length.

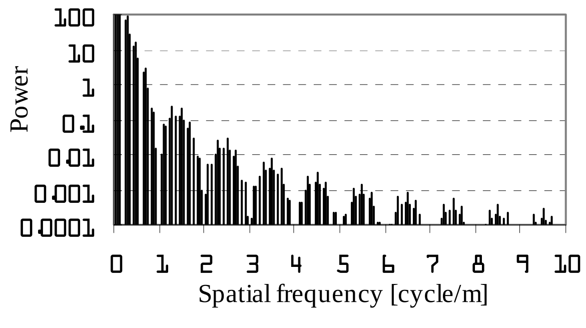

Fig. 1 The power spectrum for a simple brightness distribution model

These periodic components may be analyzed by some detection method like as edge or peak detection, but these methods have uncertainty caused by brightness noise. We employed 2nd Fourier transformation to the 1st order power spectrum domain, the power spectrum of 2nd Fourier transformation become a function of length domain.

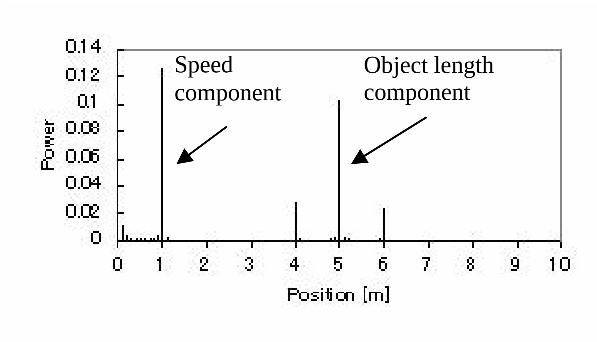

Fig. 2 Frequency components on power spectrum envelope.

Fig. 2 shows an example of frequency components on the 1st spectrum domain which was calculated by 2nd Fourier transformation for a model of simple rectangular object shape. There are speed component, object length component and two sideband components.

3. MEASUREMENT ON THE SPATIAL FREQUENCY DOMAIN

The previous result means the ability to measure speed and object shape on the frequency domain if these frequency components will be detected individually. That is, moving distance component vT in the exposure time T should be shorter than lower sideband component $L-vT$. This relation is shown as,

$$vT << L/2 \quad (5)$$

and it is a fundamental requirement to resolve speed component. If this condition will not satisfy, the speed component cannot detect clearly.

The advantage of this method is detection of the frequency components without concerning brightness intensity. This distinctive feature is useful for the various measurement objects or poor background surroundings for measurement. And decreases of fluctuation of brightness distribution are achieved on the frequency domain because Fourier transformation is based on the integral operation. But it is difficult to discriminate these components only on the frequency domain in case of brightness distribution has large scale fluctuation which is neighbouring to speed component. This difficulty will be solved by filtering on both of spatial length domain and spatial frequency domain.

The many kinds of filters for image processing have been reported, the morphology filter is one of them [2]. This filter is used to eliminate the lack of pixel elements on the video planes by means of expansion and erosion of pixel clusters though it behaviour is nonlinear characteristic and non- reversibility. This behaviour is useful to eliminate partial brightness drop caused by brightness noise or shadows by unevenness of object shape. The disadvantage of proposed measurement method will be solved by the employment of this filter to satisfy (5).

4. PRACTICAL APPLICATION TO AUTOMOBILE TRAFFIC FLOW

In the experiment, the frequency domain measurement method was applied on the automobile traffic flow measurement to measure speed of the vehicles. The practical measurement was carried out using the video frame memory and numerical discrete Fourier transformation processing.

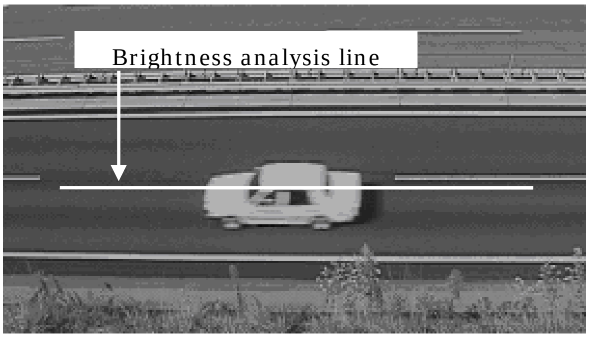

Fig. 3. The situation of speed measurement.

The surrounding situation for the measurement is shown in Fig. 3. The brightness sample was chosen on the line in Fig. 3 which length is 16.5m and pixel numbers are 500 points. The brightness analysis was done for average brightness of 4 video fields to achieve more high accuracy though usual field rate is 1/60 sec. This treatment makes longer moving distance as supposition to reduce pixel size error.

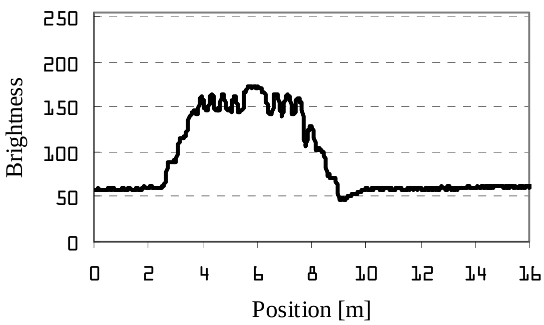

Fig. 4. An average brightness distribution of 4 video fields for a moving vehicle.

Fig. 4 is a sample brightness distribution to analyze object speed which made from 4 video fields. The gradient components are appeared at front end and tail end of a vehicle, and these parts correspond to moving distance in exposure time *T* though some unevenness noises are involved. The power spectrum for Fig 4 by the discreet Fourier transformation is shown in Fig. 5. The some periodic feature is observed on the power spectrum chart though it is not clear, and it feature diminishes on high frequency region.

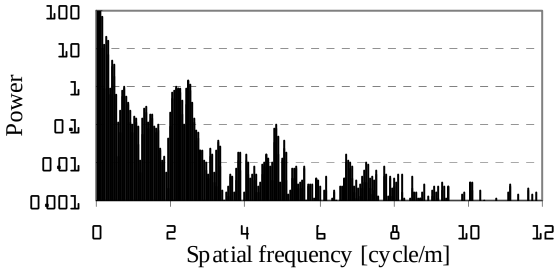

Fig. 5. The power spectrum for average brightness distribution with non-pre-processed.

The power spectrum for Fig. 5 of non-pre-processed brightness distribution by 2nd Fourier transformation is shown on Fig. 6. Though a certain peak spectrum appears at around 0.5m corresponds to vehicle speed there are many spectrum components appear elsewhere. And comparatively large component which has mean fewer components appears at around 3m. It is difficult to determine object speed on this chart. These are caused by unflatness or unevenness of brightness distribution. These unflatness are regarded as short components so the fundamental requirement (5) is not satisfied. It is difficult to determine object speed on this chart. We have to suppress these mean less components.

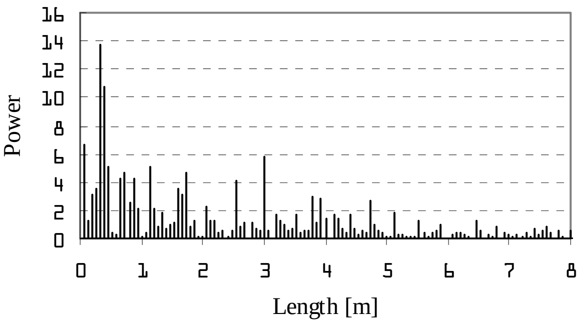

Fig. 6. Frequency components on 1st order power spectrum envelope.

Though there is one method to suppress unflatness by low pass filters, it is difficult to suppress enough with maintain periodic feature at high frequency region. More over, it is too difficult to maintain the gradient characteristics at front end and tail end of an object because these parts are determined by object speed. The filter should be kept secure the gradient characteristics and make flatness. The morphology filters usually used to image processing are employed to inspect the industrial materials by detection of lacks on a binary image [2]. This algorithm is elimination of lack by expansion of original figure and restoration of original figure by erosion. This algorithm will be applied to the proposed speed measurement.

There are many brightness drops to amplitude direction in Fig. 4 and these drops make existence as short objects, and these make bad influence to Fig. 5 and 6. These brightness drops will be diminished by expansion to horizontal direction. Fig. 7 is an expanded result from Fig. 4 which expansion length is 1.5m to both sides. It shows clear trapezoidal figure which keeps gradient components. These gradient components are similar to Fig. 4.

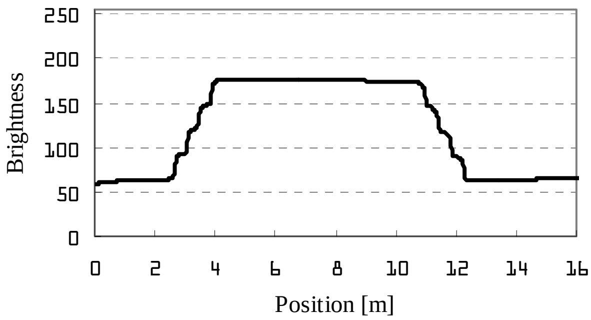

Fig. 7. The average brightness distribution using morphology filter.

So the fundamental requirement (5) is satisfied, the discrete Fourier transformation was applied to Fig. 7. The periodic feature is appeared more clearly rather than Fig. 5 as Fig. 8. Though the periodic feature was seen on low frequency range, this peculiarity was not clear on high frequency range. It requires to select up the periodic feature to achieve more reliable measurement, the weighting function of Hanning window were applied on 1st order frequency domain as Fig. 8. The Hanning window is one of useful filter to cutout the signal region with smooth cutout characteristics to have small side rove. The cut out region on the 1st order power spectrum were 10 cycle/m on this experiment as Fig. 8 because periodic feature disappears over this region

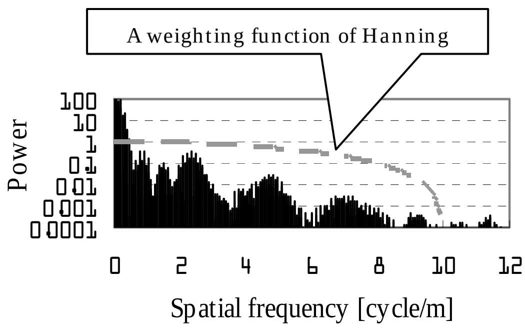

Fig. 8. The power spectrum for the brightness distribution and weighting function.

Fig. 9 is a cutout result. The spectrum components over 10 cycle/m were diminished as a matter of course, and also frequency compensation function for frequency decay factor $1/f^4$ appears in (4) was applied as Fig. 9.

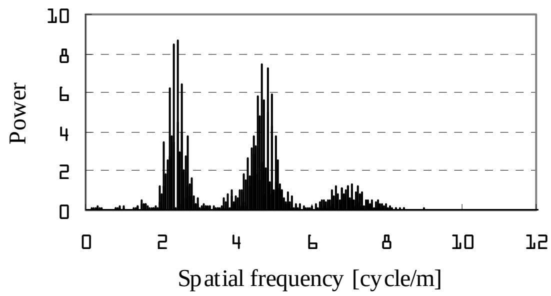

Fig. 9. The processed 1st order power spectrum.

The periodic feature appears clearly in Fig. 9. The main period is about 2.5 cycle/m and short period is about 0.12 cycle/m. The main period corresponds to object speed and short period corresponds to expanded object length. And there are no useless components.

The 2nd Fourier transformation on the spatial frequency domain to assure this periodic feature was applied on Fig. 9 and this result is shown as Fig. 10.

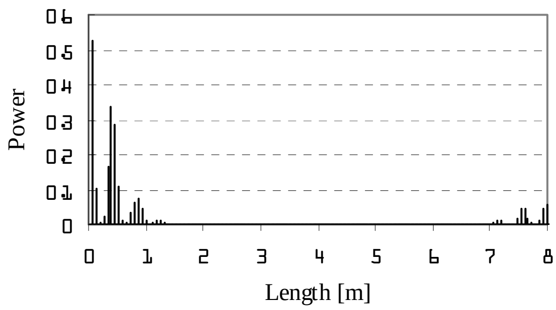

Fig. 10. The frequency components on power spectrum envelope.

So the unnecessary frequency components are suppressed in Fig. 10 compare with Fig. 6, the speed component is detected in easy. This easiness is very important to achieve certain measurement on computer aided automatic speed measurement. This component is appeared at 0.4m, and this length is moving distance in 4 video fields. This result was equivalent to practical moving speed.

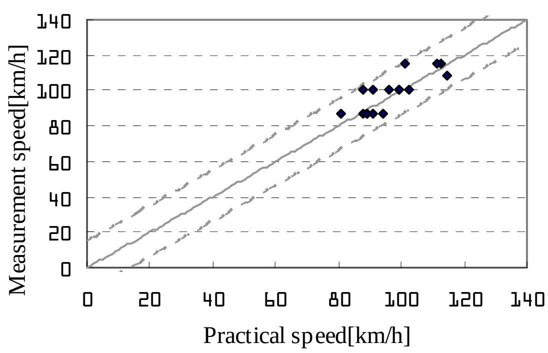

Fig. 11. Result of practical speed measurement.

Fig. 11 is the experiment result of speed measurement of vehicles on practical automobile traffic flow. The most of measured results were equivalent to practical speed which were measured by the microwave Doppler speed meter though there are many kind of colours of vehicle. These errors were not exceeding resolution band shown as two broken lines in Fig. 11 by quantization error of twice discrete Fourier transformation.

5. CONCLUSION

Though the speed measurement was attained by the Fourier analysis using some filters and measurement errors were equivalent to the sampling rate on video picture plane and frequency domain plane for the typical measurement condition, the difference of measured speed and practical speed is not so little on other case. It was caused by mismatch of the filter constants which ware settled through the experience. The systematical determination method of the filter constants on this method must be examined to the practical applications, and moreover, the relation between processing speed and measurement accuracy must be cleared.

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Authors: Prof. Tsunehiko Nakanishi and Ass. Prof. Kozo Taguchi, Department of Electrical Electronic Engineering, Faculty of Science and Engineering, RITSUMEIKAN University, Noji-higashi Kusatsu Shiga 525-8577 JAPAN, E-mail:nakanish@se.ritsumei.ac.jp