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AN OBSERVATION METHOD OF MOVING OBJECTS ON FREQUENCY DOMAIN

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Abstract - The indirect measurement methods like as image processing measurement are preferably used on the factory automation system because the complex data processing are requested on higher level measurement. On this case, the video system is regarded as the transducer, signal transmitter, signal conditioner and interface unit for a computer, and this system requires low costs by the mass production effect and has easiness of handling.

On higher-level measurement, electric quantity must be changed to appropriate projective space though the electric quantity is directly used in the usual measurement such as time domain. The Fourier transformation is an example of the higher-level measurement; and is to change time domain to frequency domain. One of the frequency domain methods to measure object movement using image processing method is shown in this report.

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

1. INTRODUCTION

The observation of an object is done only partial projective space though the measurement objects has many side profiles. The objects characteristics may be grasped on a partial projective space in some case, but the most of case is not enough because the information on a finite domain contains noises or some disturbances or uncertainties. A mission of the measurement scientist is research of way to get good measurement results. The other wards, the measurement science is called as the pursuit of survey for good measurement space. An appropriate projective space should be selected for the practical measurement [1]. The noises or uncertainties might be reduced using some filters on the other projective space by the employment of appropriate projective space.

The survey of the projective space requires some mathematical skills. So the mathematics educations are requires for the scientists and also understandings the relation between physical meanings and mathematical expression for the technological engineers on the scientific education. These concepts are well-known to the most of the educator on the technical institute. But college students will not attempt to understand these concepts because the mathematical expressions had been educated as one of academic discipline.

On the measurement education, the mathematic “function” are not merely relation between variables also the mapping relation between the objects. The intuitional sense will be acquired in the education where not only conceptual thinking or lectures but practical examples and practical applications are given. This concept is important for the measurement scientists and engineers to develop a new measurement system. The one of example is shown in this consideration to practice this concept.

An image processing measurement method are employed on the industrial site especially to measure or observe something of moving objects such as geometrical size or moving speed of the objects using non-contact measurement method. An automobile flow measurement is one of examples of this method. An object size on a video picture plane appears as brightness distribution, which 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.

The spatial frequency spectrum made by Fourier transformation is the projective space of a measurement object. Though this transformation is useful to select the required information from a lot of unnecessary information or noises, it is not enough to eliminate another noises such as brightness noises or shadows. An appropriate projective space and noise elimination filters should be employed in the practical measurement as same as usual measurement.

The many kind of filters for the 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 clusters. One of typical result of employment of these filter and transformation on the moving object observation using image processing method are presented on this report.

2. FOURIER SPECTRUM OF MOVING OBJECT

On the industrial site, non-contacting method such as image processing method is required to measure the geometrical length of a moving object. In the ordinal method, the length of an object on the video plane is measured by detection of edges of the object. It is not easy to set up the brightness threshold level to detect the edges. The threshold level depends upon brightness difference between background and object, and the brightness noise should be considered. This method is preferably adopted on suitable lighting conditions for the efficient measurement, but it is not so easy on the industrial site. And more over, the influence of vagueness of edge occurred by bluer effect depend on frame making time of video picture for the moving object should be considered. Thus the direct evaluation of brightness amplitude is too difficult on the image processing measurement.

The spatial frequency spectrum of an object on the video plane signifies both of brightness and shape of the object. The spectrum amplitude corresponds to brightness difference and the shape of the spectrum envelope corresponds to the geometrical shape of the object. The frequency spectrum of brightness on an arbitrary line of the video plane signifies the cross section length of the object, and the envelope shape of this spectrum has a periodic feature.

Hereby, we chose the vehicle as a moving object and try to calculate of the speed. Fig.1 shows a figure which vehicle from right above. Fig.2 is a simplified brightness distribution model $g(x)$ on a doted line part shown in Fig.1, where H is the brightness difference between background and a vehicle, W is vehicle length, S is the sampling section. The dimensions of W and S are given by meter. The Fourier spectrum $G(f)$ is derided as,

$$\begin{aligned} G(f) &= \int_{-\infty}^{+\infty} g(x)\exp(-j2\pi fx)dx \\ &= \left\{\frac{H}{\pi f}\sin(\pi Wf)\right\}\exp(-j2\pi f\tau) \end{aligned} \quad (1)$$

and the envelope shape of the power spectrum $P(f)$ for the rectangular brightness distribution is given by (2).

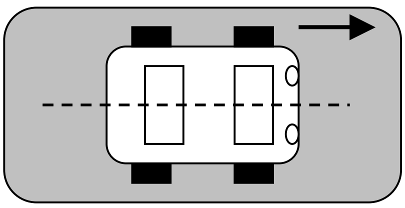


Fig.1 The vehicle photographed from right above

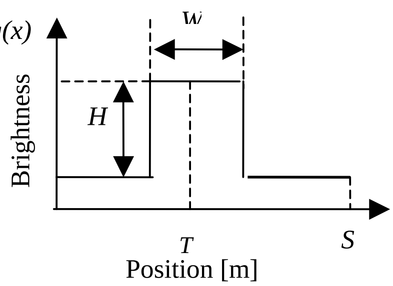


Fig.2 Brightness analysis of the dashed line part of Fig.1

$$P(f) = \left\{\frac{H}{\pi f}\sin(\pi Wf)\right\}^2 \quad (2)$$

where f is spatial frequency and dimension of (5) is given by cycle/meter. The function $P(f)$ has a periodic feature whose period is $1/W$. The information of the object's position on the video plane is not indicated in the spatial frequency domain because the phase information disappears in the process of power spectrum derivations. So we can measure object length using period analysis on the frequency domain. This analysis is achieved by Fourier integral operations too on the frequency domain.

Suppose that this vehicle is moving at speed v [m/s], and a vehicle is photographed with exposure time for T [sec]. The average brightness distribution at that time becomes as,

$$h(x) = \frac{1}{T}\int_0^T g(x - vT)dt \quad (3)$$

and it is shown in Fig.3. The Fourier spectrum for this brightness distribution is calculated as,

$$\begin{aligned} H(f) &= \int_{-\infty}^{+\infty} h(x)\exp(-j2\pi fx)dx \\ &= \left\{\frac{1}{\pi vTf}\sin(\pi vTf)\right\}G(f) \\ &= \left\{\frac{1}{\pi vTf}\sin(\pi vTf)\right\}\left\{\frac{H}{\pi f}\sin(\pi Wf)\right\}\exp(-j2\pi f\tau) \end{aligned} \quad (4)$$

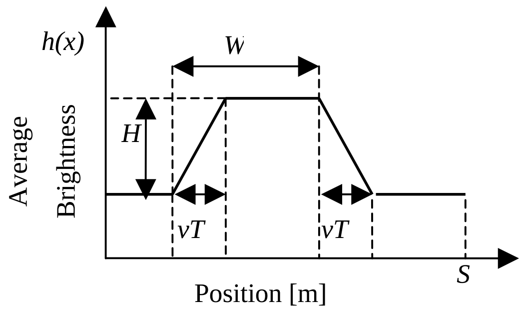


Fig 3 Average brightness

The envelope shape of the power spectrum $Q(f)$ for the rectangular brightness distribution of moving object is given by (5) using the substitution integral and norm operation calculus.

$$\begin{aligned} Q(f) &= \left\{\frac{1}{\pi vTf}\sin(\pi vTf)\right\}^2\left\{\frac{H}{\pi f}\sin(\pi Wf)\right\}^2 \\ &= \left(\frac{H}{\pi^2 vTf^2}\right)^2\left[1 - \cos(2\pi vTf) - \cos(2\pi Wf) + \frac{1}{2}\cos 2\pi(W \pm vT)\right] \end{aligned} \quad (5)$$

Where v is speed of moving object and T is averaging time of brightness information that is called frame time of video system. The first term in (5) shows periodic feature too concerning to speed. The function $Q(f)$ has a periodic feature whose periods are $1/W$ and $1/vT$. This spectrum envelope is carried out to sum of sinusoidal function and has the properties of even function. So the speed is measurable by analyzing the periodicity of the speed component contained in (5). And speed can be found on traveling distance vT divided by averaging time T.

In order to verify whether it is actually computable, the Fourier analysis to this brightness distribution is performed using a model as shown in Fig.4. It is a model figure when this figure sets object length to 5[m] and moving speed to 20[m/sec] (=72[km/h]) and averaging time to 0.05[sec]. The result of the Fourier analysis of Fig.4 becomes Fig.5. A periodic feature depend on speed has the cycle of 1/(20*0.05)=1[cycle/m], and the object length component has the cycle of 1/5=0.2[cycle/m] are shown in Fig.5. A Fourier analysis to find the periodicity is performed once again to the result of Fig.5, and periodicity will be clarified. However, the attenuation ingredient f is contained in the (5). In order to remove this attenuation ingredient, multiply compensation by f^4 to (5). The result of second Fourier transformation to obtain the periodic term from power spectrum domain is shown in Fig.6. In a model figure of Fig.6, an attenuation ingredient is compensated to the spectrum of Fig.5. This spectrum distribution consist of 4 components, the 1st is speed component, 2nd is object shape component and 2 of small are side components caused by the product operation of previous 2 components as similar to usual modulation function.

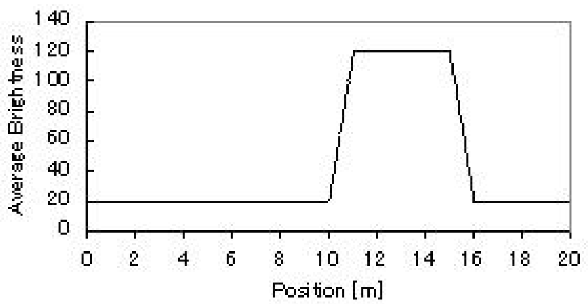


Fig.4 The model of average brightness

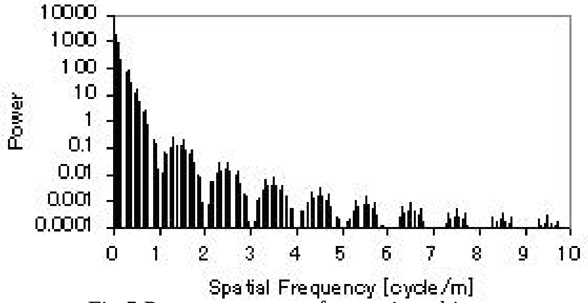


Fig.5 Power spectrum of a moving object

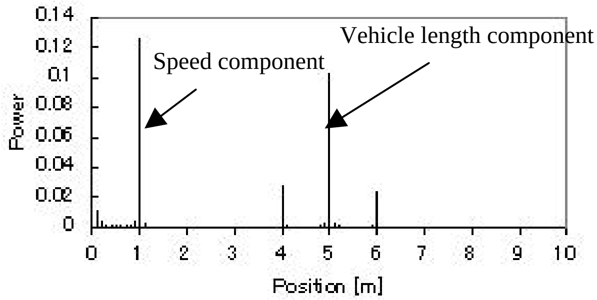


Fig.6 Frequency components on power spectrum envelope

It turns out that four peaks have come out from Fig.6. The spectrum components of which the peak has come expresses speed with 1[m], and other of which the peak has come expresses object length with 5[m]. If the component 1[m] is divide by average time, it is possible to find the speed 20[m/sec] (=72[km/h]).

As mentioned above, it was shown that it is possible to compute speed using a Fourier analysis on theoretical deployment and a model figure. The peculiarity of this measuring method is not using mere brightness quantity but periodic feature; it means that measuring accuracy is not depended on brightness conditions. It is useful on the industrial site with various kinds of objects. With the following section, it verifies whether speed measurement of a model vehicle under moving can be performed.

3. AN APPLICATION FOR A PRACTICAL MOVING OBJECT

The speed measurement was performed using a scale model vehicle as shown in Fig.7. The specification of vehicle length is 4.6[m], moving speed is 64[km/h] concerned with 1/32 scale ratio, and flame making time is 1/15[sec] that is brightness average in 2 flames of video system. The average brightness distribution on the measurement line of Fig.7 becomes as it is shown in Fig.8. The analyzing term of brightness analyzing line (sampling section) is 20[m] to reduce aliasing error, it means the frequency resolution is 0.05[cycle/m] and Nyquist frequency is 10[cycle/m]. The spatial frequency envelope, which carried out the 1st Fourier analysis of an average brightness of Fig.8 is shown in Fig.9. The periodic feature slightly appears on the low frequency range. In order to make periodicity easy to check, the same compensation concerning frequency attenuation as previously is carried out, and the periodic components was analyzed by the 2nd Fourier transformation as shown in Fig.10.

Since power components appear in more various places in Fig.10, the peak showing a speed component and length component ware undetectable. The peak value should actually be shown on the position (1.18 [m]) of the arrow of Fig.10. An undetectable cause is considered that the portion that has put the noise from a picture and the round mark of Fig.8 has affected the Fourier analysis. The mission for the engineers is to eliminate uncertainty or noise. The appropriate filters should be introduced in order to abolish these causes during the consideration of unreasonably.

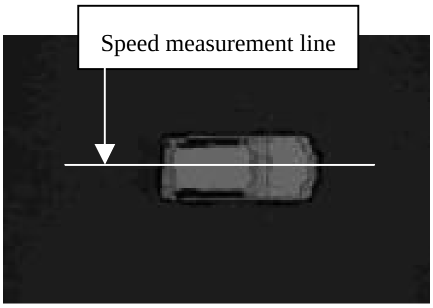


Fig.7 The situation of speed measurement

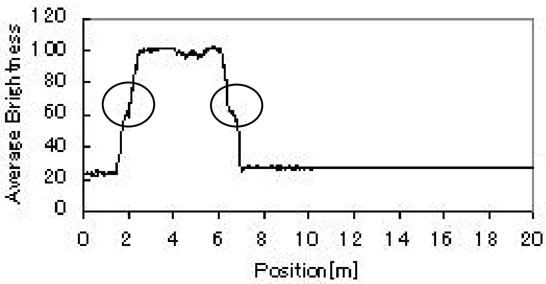


Fig.8 An average brightness distribution of model

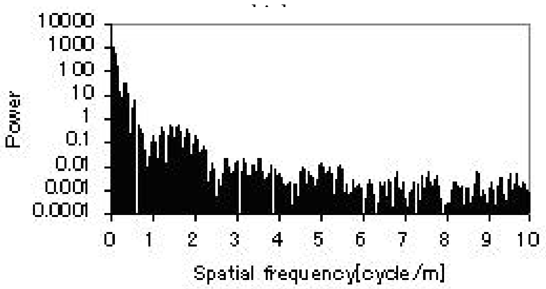


Fig.9 The result of 1st FT of average brightness

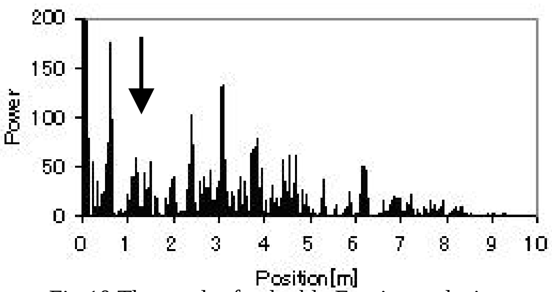


Fig.10 The result of a double Fourier analysis

4. THE INTRODUCTION OF FILTERS FOR IMAGE PROCESSING MEASUREMENT

Unfortunately our proposed frequency domain measurement has important weak points that are occurred by frequency domain operation. We employed the frequency compensation due to the frequency attenuation on the occasion to analyze periodic feature on frequency domain. This operation is equivalent to the differential operation. So the noise components are increased at higher frequency area. This situation is clearly appeared on higher frequency area and periodic properties are disappeared in Fig.9, and some forgery periodic components are appeared in Fig.10. It might be disabling to detect the correct periodic components from Fig.10. An appropriate pre-conditioning or filter for image signal has made it possible to detect the accurate results.

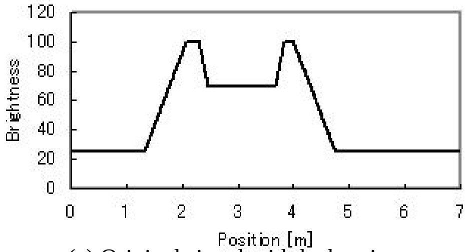
So, we decided to use 4 kinds of filters. They are time domain average, moving average on spatial position, morphology filter and window function on frequency domain.

The first conditioning is averaging on time domain. This was employed already to transfer moving distance in some frame making time as shown in (5). This filter is not enough to eliminate noise.

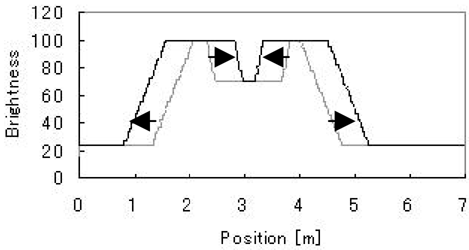
The second is moving average on position domain. This is a filter removes the random noise in a picture and is made to turn flat and smooth. It uses for removing the portions of the minute unevenness which has appeared in the average brightness distribution map of Fig. 8, and two round marks, and making them turn flat and smooth. It filters to on average brightness distribution.

The third is the morphology filter. Though the length of an object and its speed are observed on the frequency domain, this measurement method requires the regulation of separation of two frequency components. It means that the length component frequency should be bigger than twice of speed component frequency. The achievement of this regulation is not so easy because the influence of shadow and noise of an object are not so small on the practical measurement. The shadows caused by inflation or complicated shape of an object has influence as division of object size on a video picture. This is a filter used for compensating the lack part of a signal. The Fig.11 gives a principle of the morphology filter. The Fig.(a) is an original signal that contains lack noise caused by partial brightness drop, and this is divided into two parts by signal lack. This partialness is avoided by expansions of several times as (b) and (c). Finally, the expanded signal is restored by erosion of same quantities as (d). It uses in order to prevent judging shorter than practical vehicles length for partial brightness fall by the windshield, because it is for preventing the overlap showing speed component and vehicles length component. It filters to the average brightness distribution after carrying out moving average processing.

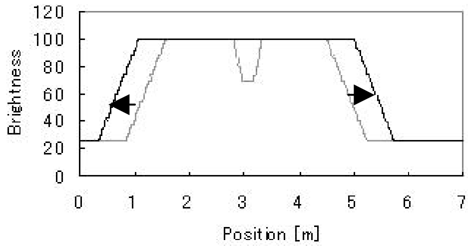
The forth is window function on the frequency domain to restrict unnecessary frequency components. The unnecessary components are increased because of compensation of frequency attenuation ingredient by f^4, and it interferes with the detection of periodicity of power spectrum. So, it uses for removing high frequency components, and filters after the Fourier analysis of an average brightness distribution. Here, Hanning window is used.



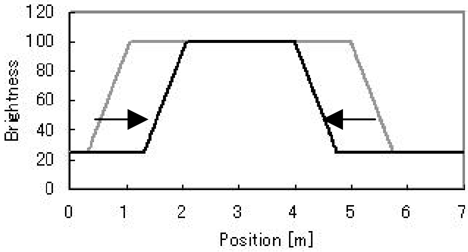
(a) Original signal with lack noise



(b) Expanded signal



(c) Second expansion



(d) Restoration by erosion

Fig.11 An outline of morphology filter

The result that used four kinds of filters is shown below. Speed measurement is performed like previously using a scale model vehicle. The conditions of vehicle length, speed and frame time are the same. The average brightness distribution on the measurement line of Fig.7 becomes as it is shown in Fig.8. A moving average filter is used for the average brightness distribution. The result with moving average filter becomes as it is shown in Fig.12. Then, the morphology filter is used for average brightness distribution of Fig.12. This result becomes as it is shown in Fig.13. The signal lack by partial brightness drop is clearly disappeared. Fourier analysis is performed to the average brightness distribution after using moving average filter and morphology filter, and the result is shown in Fig.14. The higher frequency components with no periodic feature appear on this spectrum. Hanning window is used after carrying out f^4 compensation for the data of Fig.14. The weighting function by Hanning window is shown in Fig.14. The result becomes Fig.15. A Fourier analysis is performed for the Fourier spectrum after using Hanning window once again. The result becomes Fig.16.

The data shown in Fig.16 is clearly indicated that it is easy to detect a speed component though side lobe is not so small. Since using a filter erased the noise, speed of the model vehicle was attained.

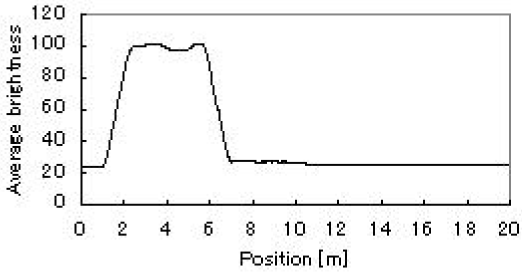


Fig.12 The average brightness distribution on moving average

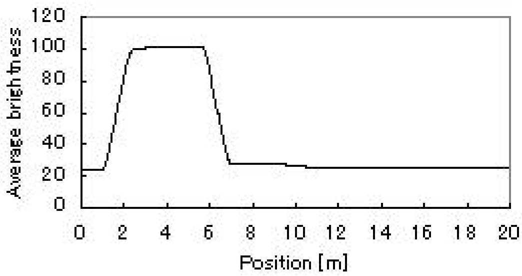


Fig.13 The average brightness distribution on morphology filter

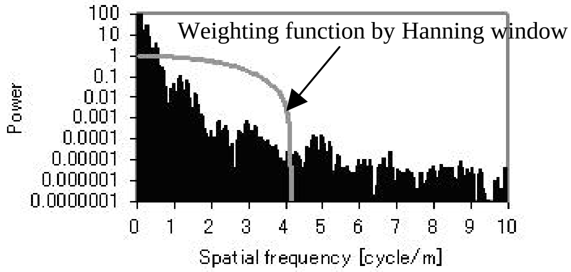


Fig.14 The result of 1st FT of average brightness distribution

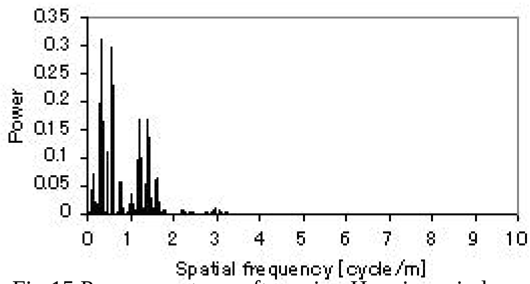


Fig.15 Power spectrum after using Hanning window

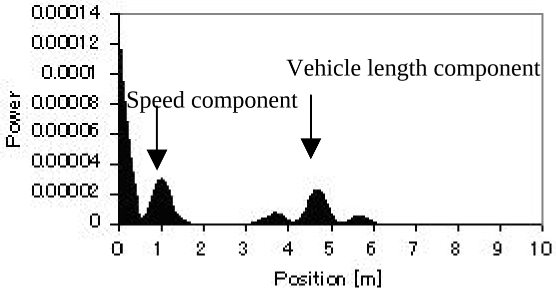


Fig.16 The result of double Fourier analysis

5. CONCLUSIONS

Using a filter attained the speed measurement by the Fourier analysis. However, the difference of measured speed and practical speed is not so still. So we have to improve accuracy of this system. Moreover, it is the subject that should be examined also about the determination method of the filter constant of the filter used here. When actually using this equipment, it may have to take into consideration. It is processing speed. It will become the problem that must also solve shortening of processing speed so that it can measure on real time.

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