AN OBJECT SHAPE AND ITS FOURIER SPECTRUM ON IMAGE PROCESSING MEASUREMENT

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

Abstract: Sometimes indirect measurement methods are preferably used though basic measurements are achieved in the direct methods. The main scheme of an indirect measurement is a decision of an appropriate transducer. The transducers and methods of them have been shown in many textbooks of measurement engineering, and most of physical quantities are changed to electric quantity by higher order transformation on intelligent measurement methods.

In higher-level measurement, electric quantity must be changed to appropriate dimension though the electric quantity is directly used in the usual measurement such as time domain. The amplitude probability density distribution analysis and Fourier transformation are examples of the higher-level measurement; the former is to change the time domain to amplitude domain and the latter is to change time domain to frequency domain. An appropriate projective space should be selected in the practical measurement. One of the frequency domain methods to measure an object shape using image processing method is shown in this report.

Key words: spatial frequency, image processing, non-contact measurement

1 INTRODUCTION

The strict theory of Fourier transformation algorithms is required in the scientific education. However, the intuitional sense is also required in the measurement, because the measurement objects have many projective spaces and an appropriate measurement should be carried out for an appropriate projective space. The intuitional sense will be acquired in the education where not only conceptional lectures but practical examples and practical applications are given. One of the applications is shown on this report; that is the image processing method. These measurement methods are employed on the industrial site especially to measure something of moving objects, such as the size of the objects. An automobile flow measurement is one of the examples of this method. A vehicle size on a video picture plane appears as brightness distribution, which is one of the projective spaces of the measurement object. Further more, the spatial frequency spectrum of brightness distribution is also a projective space of the object. An appropriate projective space should be selected for the practical measurement.

The spatial frequency spectrum made by Fourier transformation is the projective space of a measurement object. These transformations are necessary to pick up the required information from a lot of unnecessary information or noises.

2 FOURIER SPECTRUM

An arbitrary periodic function is transformed to the trigonometrical series on some mathematical restrictions using orthogonal function theory and this transformation is called Fourier transformation. This series consists of an infinite number of the bases expressed by sinusoidal functions, which are called the harmonics. In other words, a periodic function is made up from a set of harmonics, and instantaneous values of periodic function are mapped to amplitude values of each sinusoidal function, as the linear transformation is. This theory is used on the harmonic analysis or distortion analysis for the most of the students who learn the electric and electronic course. This harmonic analysis is useful for the measurement engineering. The measurement

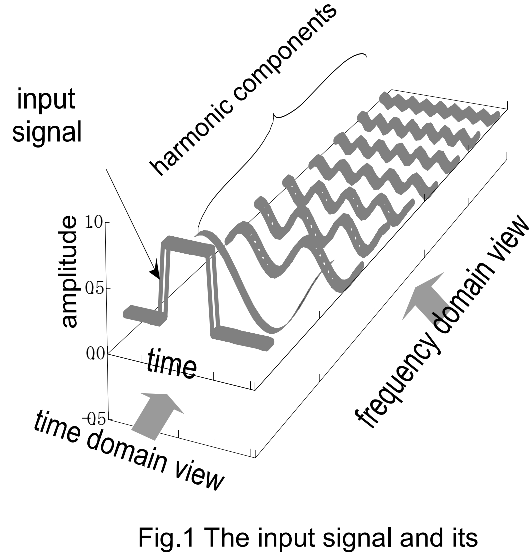

Fig.1 The input signal and its harmonic components.

engineers should recognize the usefulness of harmonic analysis in object sensing study. In case of frequency domain measurement, that is harmonic analysis method, the harmonics correspond to a projective space of the input signal from a measurement object, as shown in Fig.1. The rectangular waveform on the front end in this figure is the input signal from the sensing detector. A set of sinusoidal functions corresponds to the information of an object, and also amplitude distribution, which is observed from right hand side, does. This amplitude distribution is expressed on frequency domain.

So we can measure the object shape either on time domain view or frequency domain view. Both of them are mapping of projective spaces from a measurement object. We must chose either of them to achieve appropriate result due to accuracy, efficiency or other factors.

Generally, the amplitude distribution analysis on the frequency domain is employed for practical applications. The amplitude distribution is obtained by the integral operation, by which the fluctuational noise can be reduced.

3 APPLICATION ON GEOMETRICAL MEASUREMENT

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 detecting edges of the object. It is not easy to set up the brightness threshold level to detect the edges. The threshold level should depend upon brightness difference and background of the object, and the brightness noise should be considered. And more, the point spread characteristics of the optical system or background noises cause the difficulty of threshold level consideration. This method is preferably adopted on suitable conditions for the efficient measurement, but it is not so easy on the industrial site.

The spatial frequency spectrum of an object on the video plane signifies both of the brightness and the shape of the object. The spectrum amplitude corresponds to brightness difference, and the shape of the spectrum envelope corresponds to the shape of the object. Fig.2 is one of brightness distribution model on an arbitrary line of the video plane where W is the cross section length of an object and H is brightness of an object. The frequency spectrum of the brightness distribution signifies the cross section length of the object, and the envelope shape of this spectrum has a periodic feature. The envelope shape of the power spectrum $p(f)$ for the brightness model is given by Fourier transformation as,

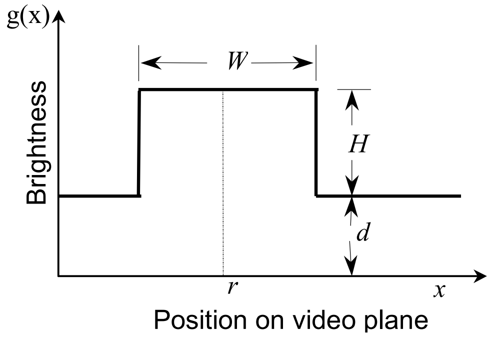

Fig.2 A brightness distribution model

$$p(f) = \left\{ \frac{H}{\pi f} \sin(\pi W f) \right\}^2 \tag{1}$$

In length measurement, the dimension of W on object plane is given by meter and dimension of f on the frequency domain is given by cycle/meter. The function $p(f)$ has a periodic feature which 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. It is said that the periodic feature of the spectrum has been mapped from object length to achieve length measurement on the frequency domain.

Further more, in case of object moving at speed V, the average brightness distribution in some duration time T becomes as,

$$h(x) = \frac{1}{T} \int_0^T g(x - V t)\, dt \tag{2}$$

and its power spectrum envelope shape $q(f)$ is derived by Fourier transformation as,

$$q(f) = \underbrace{\left\{ \frac{1}{\pi V T f} \sin(\pi V T f) \right\}^2}_{\text{envelope modification depend on speed}} \underbrace{\left\{ \frac{H}{\pi f} \sin(\pi W f) \right\}^2}_{\text{fundamental envelope shape depend on object shape}} \tag{3}$$

This spectrum consists of two terms. The 1st term shows periodic feature concerning to speed V, and the 2nd term depends on object shape as described above. Fig.3 is one of example of power spectrum envelope for the moving object which moving speed is 4 m/sec., object size is 2.5 m and averaging time is 1/15 sec. though amplitude of power were compensated by f^4 high pass filter because $1/f^4$ characteristic involves in eq.(3). There are 2 periodic components in the spectrum envelope. The long term corresponds to first term of eq.(3) and shorter corresponds to trailing term of eq.(3), that is, the long term depend on object speed and shorter one corresponds to object size.

As the period of the power spectrum corresponds to the length of an object and moving speed, the length and velocity can be measured by the period analysis of the frequency spectrum envelope. This analysis is led by double Fourier transformations. The first one is executed to obtain the power spectrum from the brightness distribution on the picture plane and the second is to obtain the periodic term from the power spectrum domain. Fig.4 shows the result of periodic feature analysis. The two distinctive spectrum peaks appear in the spectrum distribution. This is similar to the usual modulation transfer function of communication theory.

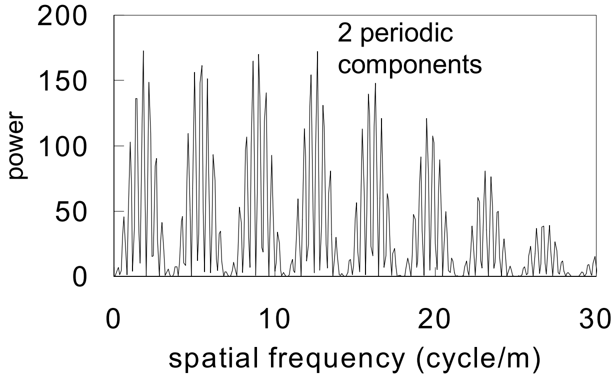

Fig.3 Power spectrum of a moving object

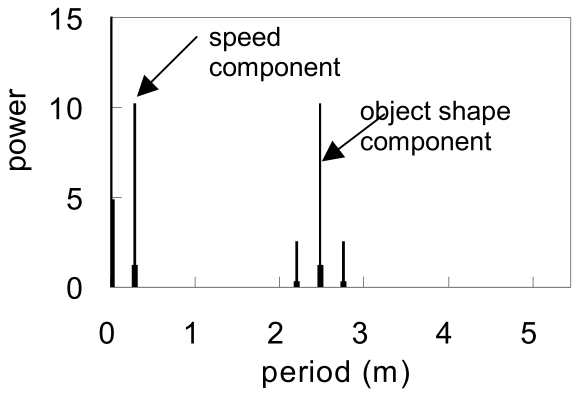

Fig.4 Frequency components on the power spectrum envelope

So the object shape measurement or object speed measurement, only search for location of spectrum peak on the period domain is required, amplitude of power quantity is not used.

In the method described above, the brightness amount is not used but only the brightness difference is. This means that lighting condition of the background is not so important. Though the edge detection method using brightness discrimination is employed as a usual image processing method, there is a significant disadvantage in the usual method. These algorithms depend on the differential operations and brightness noise causes a bad influence. On the other side, the length measurement and velocity measurement on the spatial frequency domain has the advantage of noise margin because this spectrum is obtained by the integral operations.

4 CONCLUSION

In the experiment, the frequency domain measurement method was applied on the automobile traffic flow measurement to measure the size and the speed of a vehicle. The practical measurement was carried out using the video frame memory and numerical discrete Fourier transformation processing. The measurement errors were equivalent to the sampling rate on video picture plane and frequency domain plane.