

Automotive Stereo Vision using Deconvolution Technique

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A new stereo vision system using deconvolution technique is proposed. This system is composed of the upper and the lower camera. By deconvoluting the upper image with the lower one, the system constructs a horizontal section image. After the automobiles are separated from the other things in this horizontal section image, the distances and relative velocity are measured. This segmentation is realized by the thresholding procedure which utilizes the relation between the distance and the breadth of the automobile. The experimental results are presented. It is also shown that the deconvolution technique is able to construct a finer and higher resolutional horizontal section image compared with a correlation technique. Although the SN ratio of the horizontal section image is inconsistent with range resolution, the possibility of the adjustment between the SN ratio and the resolution is presented.

1. Introduction

In order to avoid the motorcar accidents, it would be the effective method that the driver is assisted with the warnings by a computer system for safety. This system needs the sensors which detect traffic conditions. Measuring the distances and relative velocity between the driver and the automobiles around him is the most basic function of these sensors. Because of the difficulties to identify the automobiles from other things, this problem has not completely solved yet. The most important key to solve this problem is a fast processing of the horizontal section images around the driver. This horizontal section image can be obtained by a stereo vision (triangulation system) via measuring the value of the shift between two images. In order to measure the value of this shift, many techniques have been utilized (i.e. the correlation technique¹⁾, the technique which utilizes the phase shift of the narrow bandwidth of the target Fourier spectrum²⁾, etc.). This paper describes an alternative technique using deconvolution.

2. Stereo Vision using Deconvolution Technique

2-1 Obtaining the Horizontal Section Image

With the stereo vision system shown by Fig.1, it is possible to approximate the upper image $f_2(x)$ is the shifted image of the lower one $f_1(x)$.

$$f_2(x) = f_1(x - \tau) [= \int f_1(x') \delta(x' - (x - \tau)) dx'] \quad (1)$$

In other word, it can be said that $f_2(x)$ is a convoluted image of $f_1(x)$ and $\delta(x - \tau)$. By measuring the value of the shift τ , we can obtain the distance between the target ahead and the system. Therefore, one line of the horizontal section image can be obtained by plotting with light and shade the correlation curve, which is obtained by calculating the degree of matching between two images when the upper image is shifted relative to the lower one. Since the lower camera of this system always gives the front view of the targets on the road as a reference image, this camera arrangement is suited for detecting the traffic obstacles.

The algorithm to obtain horizontal section image is as follows. [see Fig.2]

- [1] Two windowed images are obtained by the upper and the lower cameras. [Fig.4(b) and (c)]
- [2] The Fourier transformations of the obtained images are carried out by FFT.

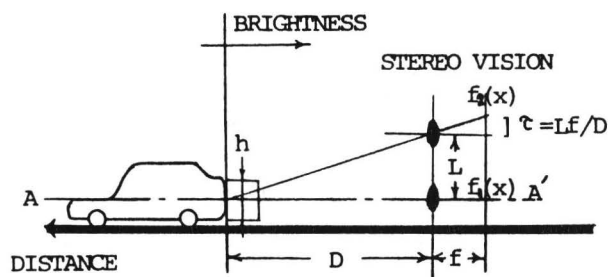


Fig.1 The principle of stereo vision

$$F_i(\omega) = \int_{-\frac{X}{2}}^{\frac{X}{2}} f_i(x) * e^{-j\omega x} dx \quad (i=1,2) \quad (2)$$

where X refers to the length of the image.
[3] By deconvoluting the upper image with the lower one, we calculate the correlation curve in the frequency domain ; G(ω).

$$G(\omega) = F_2(\omega) * D(\omega)$$

$$D(\omega) = \begin{cases} 1/F_1(\omega) & ; F_1(\omega) \geq F_{1\max}(\omega)/a \\ 0 & ; \text{otherwise} \end{cases} \quad (3)$$

where "a" [=30 for the following examples] is a constant.

[4] By the inverse Fourier transformation of G(ω), the correlation curve g_d(z) is obtained. [Fig.3(a)]

$$g_d(z) = \int_{\omega_1}^{\omega_2} G(\omega) * e^{j\omega z} d\omega \quad (4)$$

where ω₁(ω₂) is the lowest (highest) angular-frequency of the target Fourier spectrum.

Repeating these procedures ([1]~[4]) along the horizontal right/left direction, the horizontal section image is obtained. [Fig.4(d)]

2-2 Automobiles Identification and Velocity Measurement

Once the horizontal section image is constructed, the automobiles are separated from the other things by thresholding procedure which utilizes the relation between the distance and the breadth of the automobile. The result of this segmentation is presented by Fig.4(f). Finally, relative velocity is measured by processing two sequential horizontal section images.

3. Deconvolution and Correlation Technique

The horizontal section image can also be constructed using correlation technique. Assuming that the brightness distribution of the vehicle image has a square shape as shown on Fig.1, the comparison of these methods are derived.

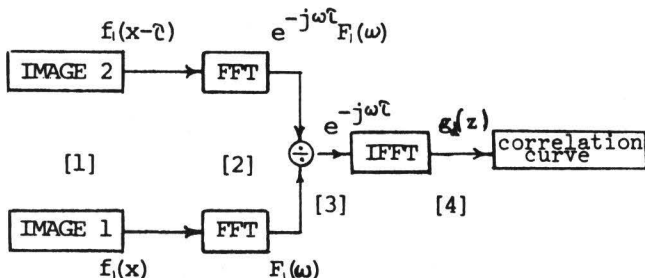


Fig.2 The algorithm of calculating the correlation curve.

3-1 Quality of Horizontal Section Image

(a) Deconvolution Technique : Substituting Eqs.(1),(2) into Eq.(4), the correlation curve g_d(z) is given by Eq.(5).

$$g_d(z) = \int_{\omega_1}^{\omega_2} \frac{e^{-j\omega\tau} F_2(\omega)}{F_1(\omega)} e^{j\omega z} d\omega = \int_{\omega_1}^{\omega_2} e^{j\omega(z-\tau)} d\omega = \frac{\Omega}{2} e^{j\Omega m(z-\tau)} * \text{SINC}\left[\frac{\Omega}{2}(z-\tau)\right] \quad (5)$$

where $\Omega = \omega_2 - \omega_1$, $\Omega m = (\omega_1 + \omega_2)/2$.

The range resolution $\delta_d [=2\pi/\Omega = h/2a$; Fig.3(a)] is generally small and adjustable by varying the value of "a".

(b) Correlation Technique : The correlation curve g_c(z) is derived as follows.

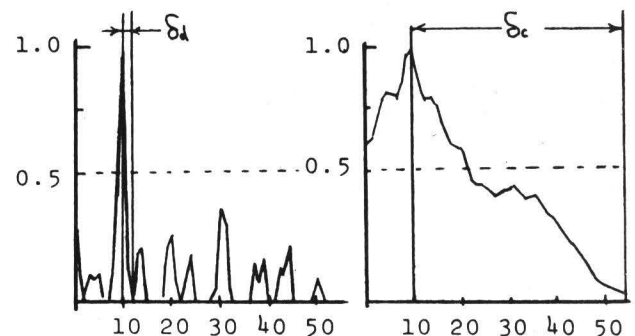
$$g_c(z) = \int_{\omega_1}^{\omega_2} F_1(\omega) * F_1^*(\omega) e^{j\omega(z-\tau)} d\omega \quad (6)$$

The range resolution $\delta_c [=h$; Fig.3 and Fig.4(d),(e)] is generally large.

Comparing these techniques, the correlation curve using deconvolution has a constant shape of SINC function, and its shape depends only upon the target Fourier spectrum. On the other hand the correlation curve using correlation depends upon the target Fourier spectrum itself. Therefore, a finer (easy to process) horizontal section image is obtainable using deconvolution technique.

3-2 Effects of White Noise

When the white noise (its power spectrum is N₀) is added to the square shaped image, the SN ratio [the ratio of peak (matching point) power to the mean noise power] of the horizontal section image is analyzed as follows 3).



(a) Deconvolution (b) Correlation

The ordinate represents the degree of matching. The abscissa represents the length of shift between two images. The two images are matched when the length of shift is equal to 10.

Fig.3 The shape of correlation curves.

- (a) Deconvolution Technique: $SN_d = 3h/\pi N_o a$ (7)
 (b) Correlation Technique: $SN_c = 2h/N_o$ (8)

Considering δ_d and Eq.(7), the deconvolution technique enable us to adjust the range resolution and the SN ratio by varying "a". It is also possible to prove that the additive white noise causes no peak position error of correlation curve by any these two techniques. In the analysis stated above, the input data is assumed to be continuous. Since real data is not continuous, the discrete calculation (FFT) brings the data a cyclic property. However, this effect can be reduced by windowing and filling zeroes around the input data.

4. Conclusions

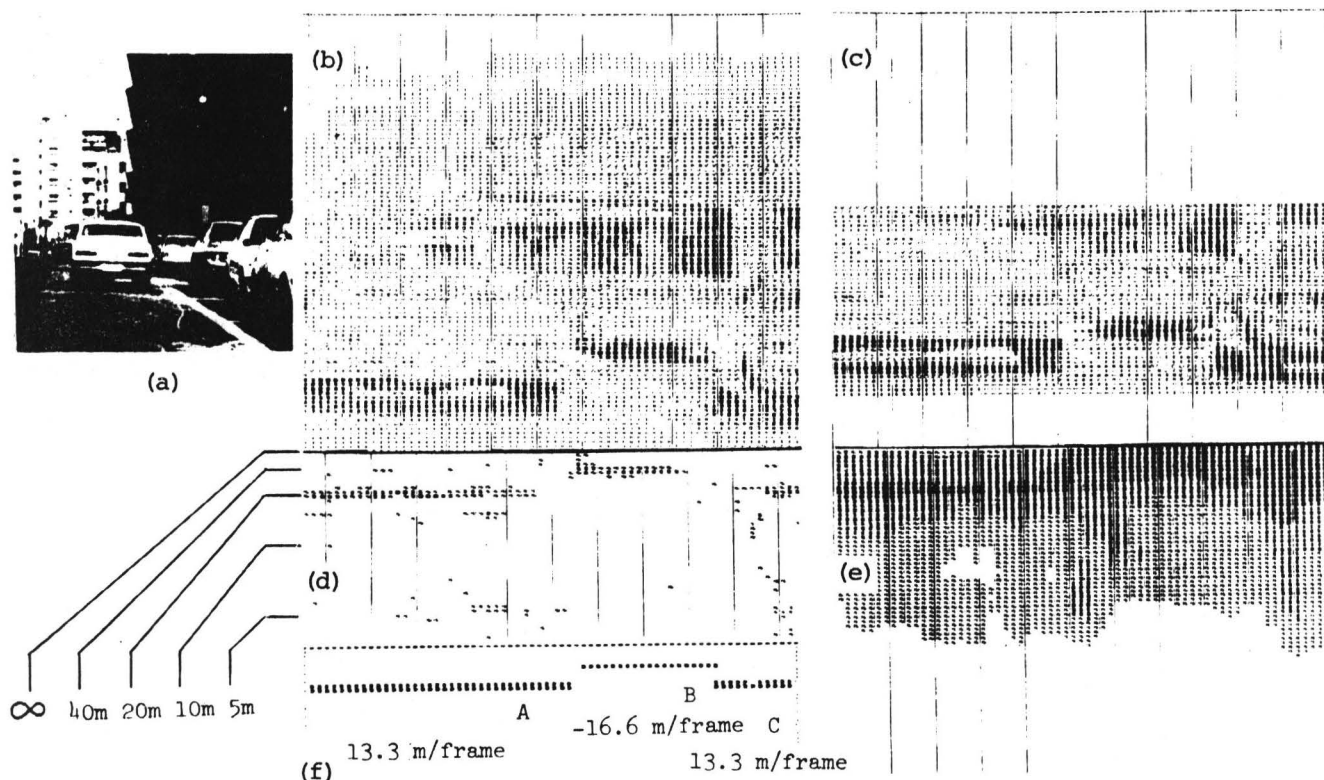
- 1] A stereo vision using deconvolution technique is proposed.
- 2] This vision system is able to construct a finer and higher resolutional horizontal section image compared with a system using correlation technique.
- 3] It is also shown that the adjustment between

range resolution and the SN ratio of the horizontal section image is easily realized by this technique.

4] The identification of the automobiles from the other things and the measurement of the distances and relative velocity between the driver and the automobiles ahead of him are presented by processing these horizontal section image sequentially.

References

- [1] Yakimovsky, Y. and Cunningham, R. "A System for Extracting Three-Dimensional Measurements from a Stereo Pair of TV Cameras" Computer Graphics and Image Processing 7, pp 195-210 (1978)
- [2] Arking, A. A., Lo, R. C. and Rosenfelt, A. "An Evaluation of Fourier Transform Techniques for Cloud Motion Estimation" Computer Science Technical Report TR-351, University of Maryland (1975)
- [3] Urkowitz, H. "Filters for Detection of Small Signals in Clutter" J. Appl. Phys., Vol.24, No.8, pp 1024-1031 (1953)



- (a) The photograph used for experiments. (b) Upper image. (c) Lower image.
 (d) The horizontal section image via deconvolution technique.
 (e) The horizontal section image via correlation technique.
 (f) The result of the segmentation of the automobiles and measurement of velocity.

Fig.4 The experimental results