APPLICATION OF THERMAL INFRARED VIDEO SYSTEM IN SPIRAL FLOW IMAGE TRACING FOR THE WATER FLOW VELOCITY DISTRIBUTION MEASUREMENT

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ABSTRACT

A system to measure river flow velocity distribution by analyzing thermal infrared video images of turbulent flow or streamwise vortex in a river has been developed. This system has the following major advantages.

(1) Because of the application of remote sensing technology currentmeters or floats are not required.
(2) By using thermal infrared band, data recording is possible even during night time.
(3) Data can be recorded automatically by installing the system on the river side.
(4) Acquired raw data can be transmitted to remote office for recording.

With these features, continuous observation of rivers is possible even during night time or in stormy weather conditions.

INTRODUCTION

River flow velocity has been measured by several kinds of techniques such as currentmeter or float.
River flow velocity measurement by currentmeter and by float in the river are the most popular techniques. In these techniques, several operators must be situated in the river or river side, and in the case of night time or stormy weather condition, they are very dangerous.
Some ultrasonic currentmeters are established at several rivers of Japan and they are used to measure flow rate. But it is not so usual because of difficulty of installment.
Cameron effect on aerial photograph can be used to measure the river flow velocity. In this case, aerial survey craft is required, however it is effective in day time only.
Radio currentmeter is available at present,but it's measurement limits is within approximately 20 meters.
Techniques of river flow measurement that is available at present have several difficulties such as the danger during observation or impossibility of measurement at night.
The objective of this study was to develop the new technique of river flow measurement that is free from the above mentioned difficulties. The developed technique can solve some difficulties and has some advantages.

METHOD

There are many kinds of uneven surface patterns of turbulent flow in river (OHNARI et al., 1985). Figure 1 shows a model of streamwise vortex that produces uneven surface pattern of river flow (KINOSHITA,1967). Those surface pattern shifts from place to place with the current, so the displacement per unit time of the surface pattern represents the mean current velocity. Figure 2 shows the relationship between the current velocity and the surface pattern displacement.

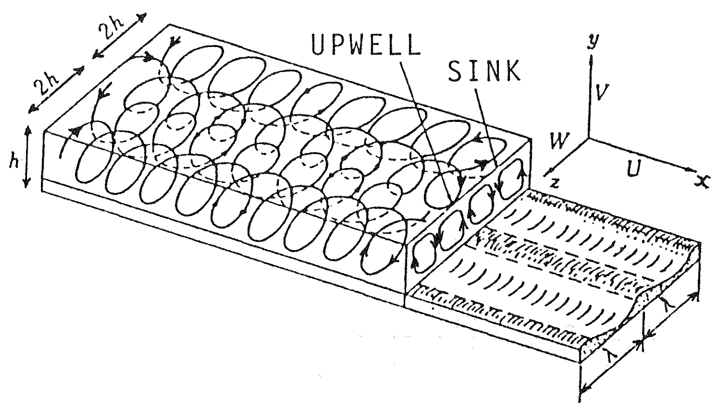


Fig. 1 A model of streamwise vortex.

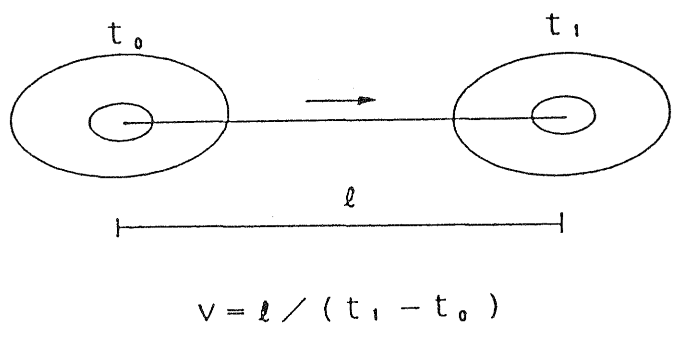


Fig. 2 A model of current pattern displacement and the mean current velocity V (m/s).
t_0, t_1:time (second), l:displacement distance (m).

The uneven surface pattern of river water has uniform temperature distribution by mixing of turbulent flow. But, the oblique thermography can detect the apparent temperature difference of uneven surface pattern of river water. Explanation of apparent temperature difference is as follows;
The hemispherical reflection (ρ), transmittance (τ), and absorptance (α) are defined by the dimentionless relation.

$$\alpha(\lambda)=1-\tau(\lambda)-\rho(\lambda), \quad (1)$$

$$\rho(\lambda)=M_{\lambda reflected}/E_{\lambda}, \quad (2)$$

$$\tau(\lambda)=M_{\lambda transmitted}/E_{\lambda}, \quad (3)$$

where:

M_{λ}:Radient exitance.
E_{λ}:Irradiance.

In the case of water surface, the reflected energy from surface consists of energy by Fresnel reflectance and underwater sctteri ng.
Fresnel reflection is given as

$$\rho=\frac{1}{2}(\rho_1+\rho_2)=\frac{1}{2}\left[\frac{\tan^2(i-j)}{\tan^2(i+j)}+\frac{\sin^2(i-j)}{\sin^2(i+j)}\right] \quad (4)$$

where:

i :Incidence angle.
j :Refraction angle.
ρ_1:Reflection coefficient for horizontal porlarization.
ρ_2:Reflection coefficient for vertical porlarization.

Figure 3 shows the relationship of water surface reflectance and incident angle.

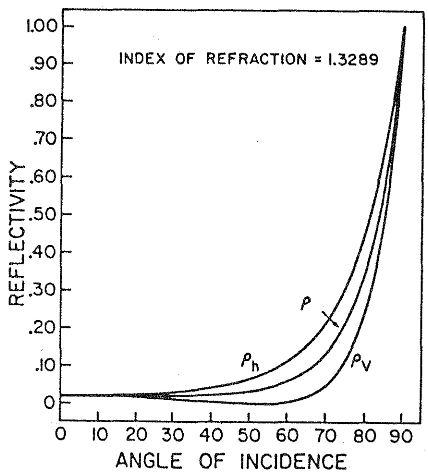


Fig. 3 Fresnel reflectivity for horizontally and vertically polarized radiation.

In the thermal infrared range, the water is apporoximate to blackbody. So it has transmittance $\tau=0$ and emits radiation. Kirchhoff's law shows that the emissivity of a body for certain wavelength is always equal to the absorptance α.
Thus, Eq,(1) becomes

$$\varepsilon(\lambda)=1-\rho(\lambda) \tag{5}$$

Radiation Rb is emitted from the blackbody in accordance with the Stefan-Boltzmann Law.

$$Rb=\varepsilon b\sigma T^4 \tag{6}$$

where:

εb:Emissivity of the blackbody.
σ :Stefan-Boltzmann's constant.
T :Absolute temperature in degrees Kelvin.

In the case of oblique thermography, the water surface emits radiation and reflect sky radiation or the opposite bank radiation by Fresnel reflection.
Those relationship is represented as follows:

$$R=\varepsilon\sigma Tw^4+\rho Ra \tag{7}$$

where:

R :Detected radiation by thermal sensor.
σ :Stefan-Boltzmann's constant.
ε :Emittance.
ρ :Reflectance by Fresnel Law.
Tw:Water temperature in degrees Kelvin.
Ra:Sky radiation or the opposite bank radiation.

In the case of nadir distance is 85 degrees, $\rho=0.6$ by Fresnel reflectance and emissivity $\varepsilon=0.4$, thermal radiation from water surface will be less than the radiation of sky or opposite bank by Fresnel reflection.
Figure 4 shows an example of measurement that is relationship between apparent temperature and angle of view (KIMURA et al. 1969).

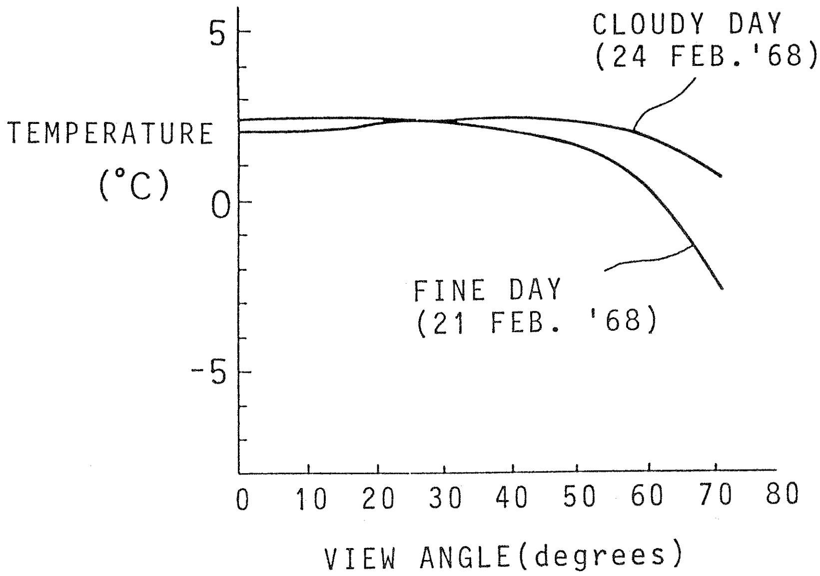


Fig. 4 An example of apparent water temperature for vaious angle of view by infrared thermometer (KIMURA et al. 1969).

DATA AQUISITION AND ANALYSIS

KOZENJI water level observatory and NANOKAMACHI observing station which the water level and the flow has been observed, were selected for this study. 35mm film camera, visible band video camera and thermal video camera were used to collect photographs, visible band video images and thermal images respectively on two separate dates in Octorber 1985 and April 1986. The night time thermographs were collected at 2000 hours on 8 Octorber 1985, and 1900 hours on 23 April 1986.

The thermal data were collected with Thermotracer 6T61 sensitive to radiation in the 8 to 13μm wavelength and Thermal Video System TVS -4500 sensitive to radiation in the 3 to 5.4μm wavelength.

Control points were established on both river side. Two points were on one side and three points were on the otherside. Signal were made of Aluminum foils or styrene foam panels that has a large apparent temperature difference to the surrounding features. Photo. 1 shows an example of those control points.

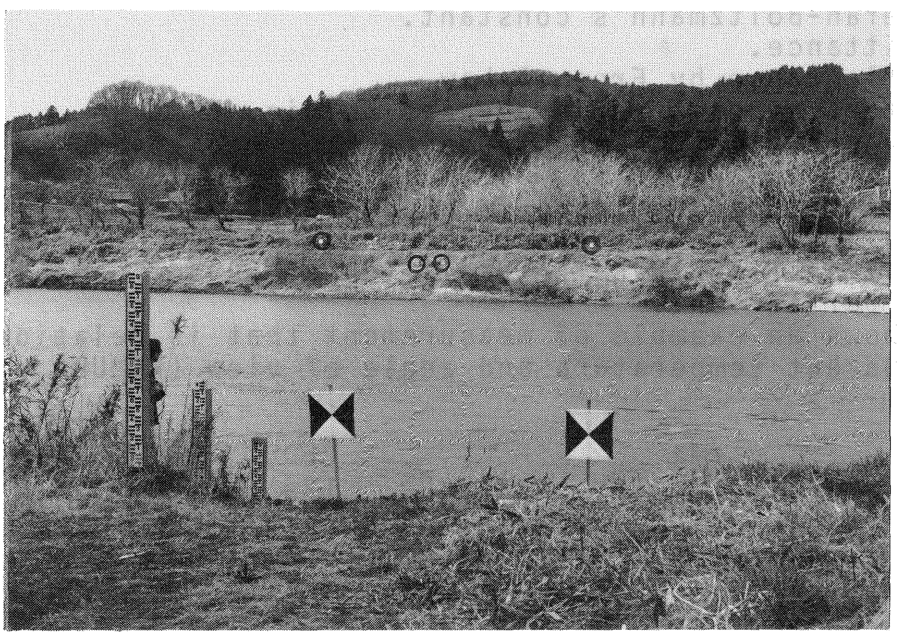
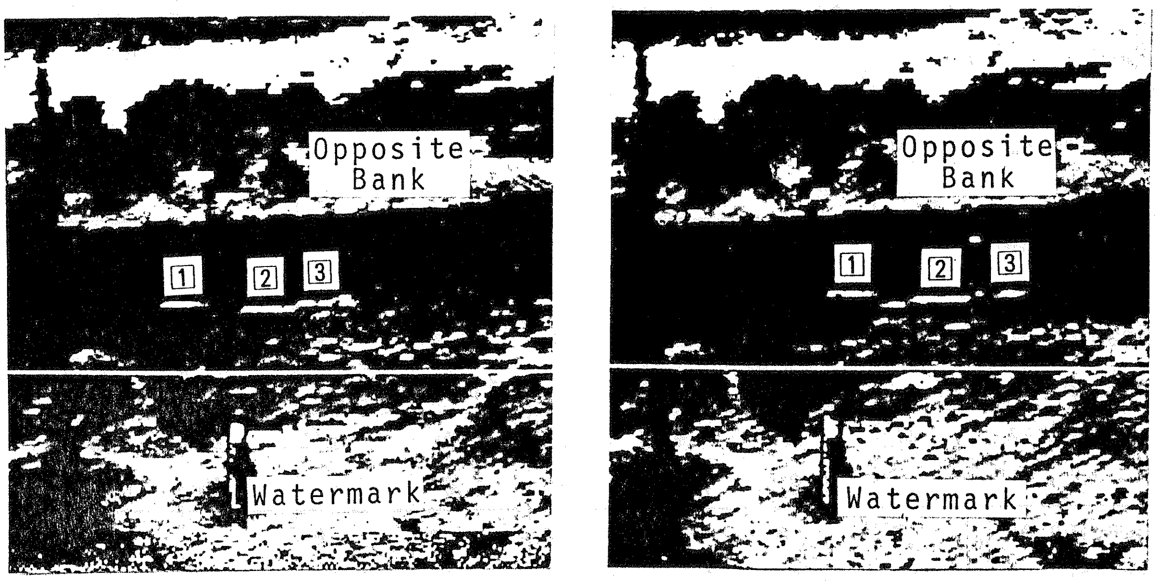


Photo.1 Established control points on both river side.

The water level and the flow were observed at the observation station while thermographs were collected. The flow were measured by the currentmeter and floats.

These data were analyzed by terrestrial non-stereoscopic techniques. The individual surface pattern was traced on sequence display image on CRT. The location of surface pattern or control points on the display images on CRT were measured by a cursor of a personal computer system or crystizer (crystal panel digitizer).

Photo. 2 shows some surface pattern on two sequence thermal images at the night time.
The displacement of surface pattern on the sequence images was measured. And mean current velocity was calculated from the displacement. The mean current velocity was compared with the velocity by currentmeter and floats.



a) 18h 39m 13s

b) 18h 39m 15s

Photo. 2 Thermographs on 8 October 1985.Displacement of three surface patterns can be seen on these thermographs.

RESULTS

Table 1 shows surface pattern displacement and mean current velocity by the thermographs and current velocity by currentmeter. It can be seen that the displacement surface pattern of each time period is not equal, which means that the surface pattern changes the shape with time and/or positioning of surface pattern's center has a possibility of an error.

Figuer 5 is the plots of those mean current velocity by thermographys against the current velocity by currentmeter or floats. It shows that there is a good correspondence of the velocity by thermograpfys and the velocity by currentmeter or floats.

Table 1. Surface pattern displacement by thermograms on 10 Octorber 1985.

Surface Pattern No.	Time	12h42m 13s	12h42m 14s	12h42m 15s	12h42m 16s	12h42m 17s	12h42m 18s	Mean Velocity	Velocity by current-meter
1	Location of Pattern	m 6.1	m 8.2	m 10.0	m 11.8	m 13.7			
	Displacement		m/s 2.1	m/s 1.8	m/s 1.8	m/s 1.9		m/s 1.9	m/s 1.47
2	Location of Pattern	m 7.5	m 8.4	m 10.0	m 10.9	m 11.9	m 13.3		
	Displacement	m/s	m/s 0.9	m/s 1.6	m/s 0.9	m/s 1.0	m/s 1.4	m/s 1.16	m/s 1.74
3	Location of Pattern	m 5.8	m 8.0	m 9.8	m 11.5	m 13.0	m 15.0		
	Displacement		m/s 2.2	m/s 1.8	m/s 1.7	m/s 1.5	m/s 2.0	m/s 1.84	m/s 1.78
4	Location of Pattern			m 7.5	m 8.8	m 10.4	m 11.6		
	Displacement				m/s 1.3	m/s 1.6	m/s 1.2	m/s 1.37	m/s 1.74

CONCLUSION

A new technique to measure river flow velocity distribution by analyzing thermographs of river surface pattern is able to give the almost same accuracy as the present techniques such as currentmeter or floats.
And furthermore, this technique has the following major advantages.
(1) This technique is able to measure the flow velocity from river bank without using currentmeter or floats.
(2) Data aquisition is possible even during night by using thermal infrared band.
(3) Data can be recorded automatically by installing the system on the river side.
(4) Acquired row data can be transmitted to remote office for recording.
By making full use of these advantages,continuous observation of rivers is feasible during day and night time automatically.

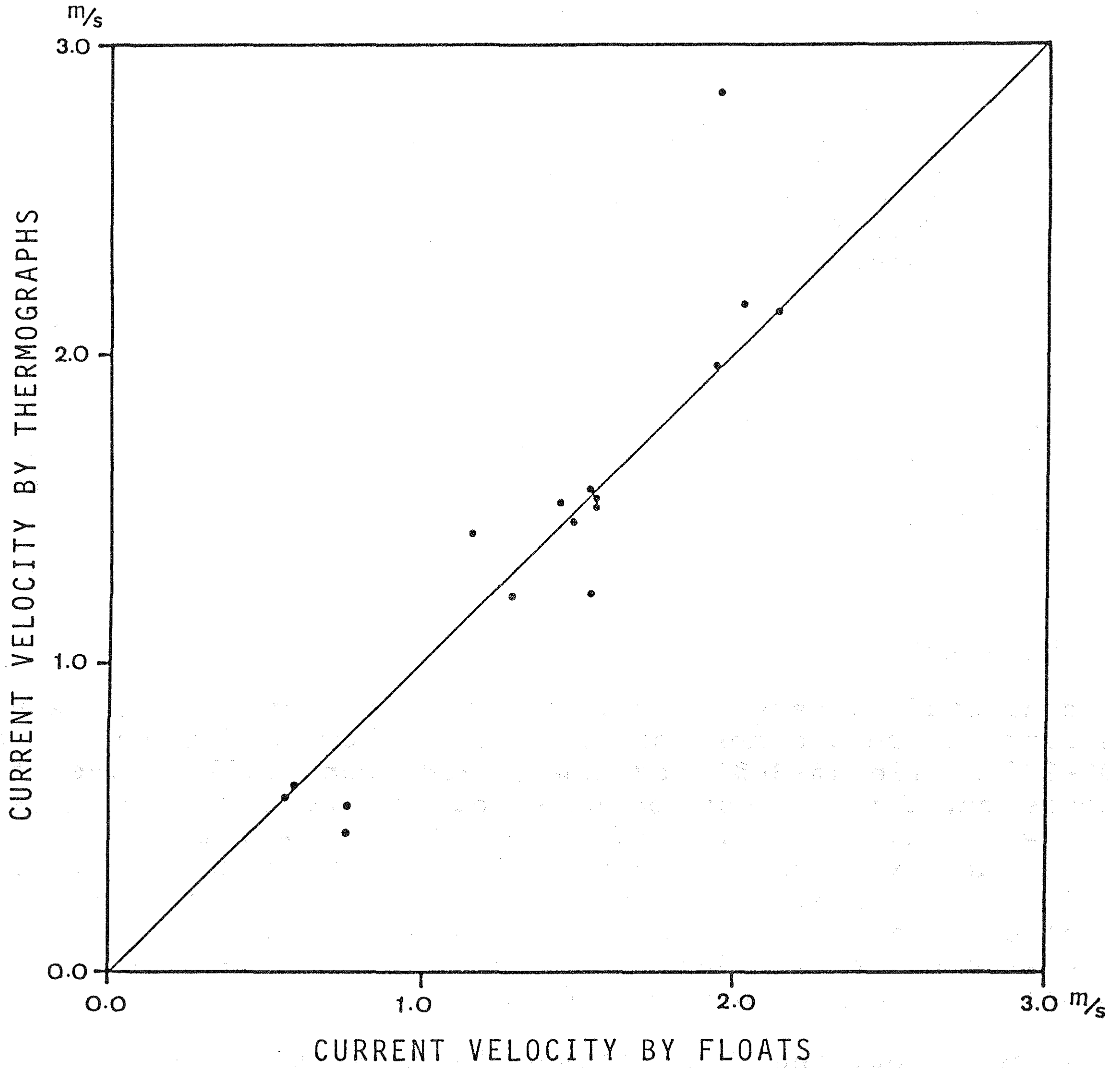


Fig.5 Mean current velocity by thermographs versus the current velocity by floats. (19 and 23 April 1986. NANOKAMACHI)

REFERENCE

1) Kinoshita, R. :An Analysis of the Movement of Flood Waters by Aerial Photography, Concerning Characteristics of Turbulence and Surface Flow (in Japanese). J.of the Japan Society of Photogrammetry and Remote Sensing, Vol.6 No.1,1967.
2) Ohnari, H., Saga, T. and Saitoh, T. : The Structure of Streamwise Vortex in the Inner Layer of Turbulent Channel Flow (in Japanese). Proceedings of Japan Society of Civil Engineers, No.363/II-4, p.135-144, 1985-11.
3) Kimura, R. and Misawa, N. : Observation of Sea Surface Temperature by the Infrared Radiation Thermometer, J.Oceanogr. Soc.Japan. Vol.26. No.1, 1969.