研 究 速 報

3D Particle Imaging Thermometry and Velocimetry (PITV) using Liquid Crystal

—4th Section; Application of 3D PITV to the Measurement of Temperature and Velocity of a Vertical Buoyant Jet—

感温液晶粒子を用いた3次元粒子画像温度・速度計測法

—第4報; 3D-PITVの垂直浮力噴流の温度・速度計測への適用—

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1. Introduction

Turbulent jets in which the discharged fluid differs in density from the ambient fluide are termed buoyant jets. They occur somewhat rarely in nature but are observed in active volcanoes and the recently discussed 'black smokers' discovered in association with rift zones in the seafloor.

Many challenges had been done for the measurement of the unvisible physical phenomena by applying the conventional probe measurement. Measurements had been done for the measurement of the time-averaged velocity at the axis of the vertical round buoyant jet by Ogino et al.[1] and time-averaged temperature by a number of experimenters, the results showing that the measured values follow a scaling law proposed by Chen and Rodi[2),3)].

However, most of the measurement were point measurement in which the reliability of the correlation between the velocity and the temperature is not sured. On top of it, for the study of the whole structure of the jet flow, there needs many probes or another consideration should be paid.

On this context, a method that is neither a point measurement and nor a correaltive method is necessarily. Therefore, in this study, the simultaneous spatial measurement method for temperature and velocity is introduced to the measurement of the thermal vertical jet on the bases of the previous three sections. In this section, simultaneous measurement for the temperature and the velocity of the vertical turbulent buoyant is stated. The optimal measurement conditions for avoiding the optical characteristic, the bragg-type scattering, are considered by adjusting the size of the measurement area, the position of camera from the measurement area, and the light source position.

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2. Application to the Measurement of a Vertical Buoyant Jet

Figure 1 shows the schematic experimental apparatus for a vertical buoyant jet. The rectangular tank is made of glass and polyvinyl and is 18×18 cm in cross section and 25 cm deep. The temperature of the warm water bath is controlled to keep the temperature of the nozzle outlet constant. The end of the nozzle is square cut and the diameter is 4 mm. The visualization is worked out by the cold light (halogen 150W) beam and the micro-capsulated liquid crystals (R23C3W) which is heated up to 30°C in the hot water bath (YAMATO BK 53) and flow into the square tank in which the temperature is maintained 22.8°C by another water bath (LAUDA RMS 6). A DC power supplier (KENWOOD PS20-18) was used for the halogen light. The mean velocity of the nozzle outlet is 0.602 [m/sec] and the water of the tank overflows to keep heat balance of the tank. The measuring region concerned is between 23d and 33d from the nozzle position. The whole absolute coordinate is based on the traverse system (THK KR type) located upper side of the tank. The ambient water temperature was also measured using a thermo-couples of which electric signal is transferred to the temperature recorder (YOKOGAWA

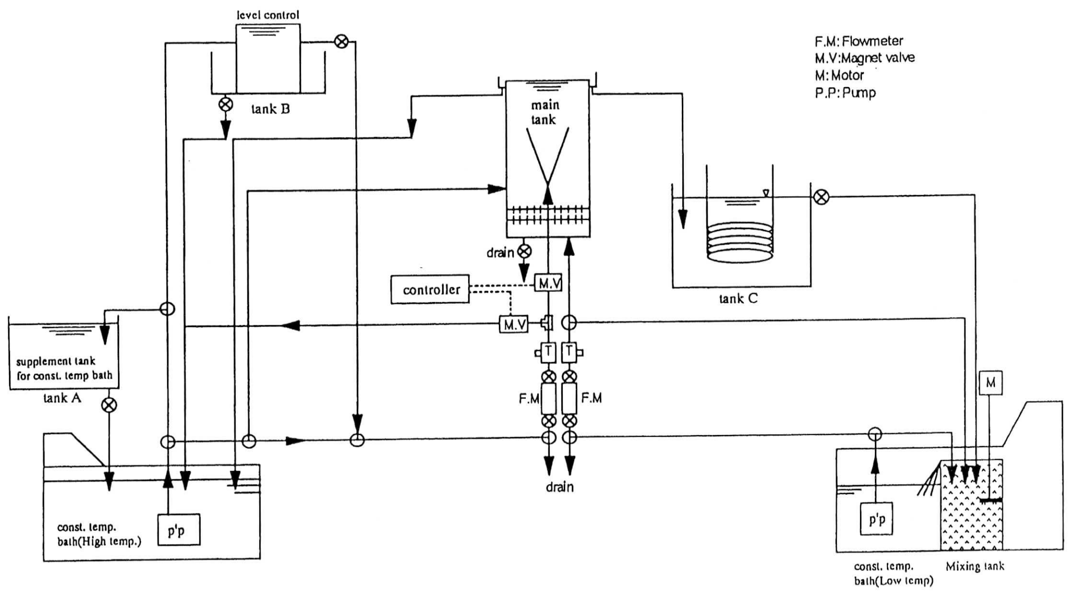


Fig. 1 Experimental apparatus

mR 180, Model 4177). Figure 2 shows the conceptual diagram of the whole experiment. The whole experimental condition is maintained without any change until the end of the experiment.

In order to measure the velocity of the nozzle outlet, half-width of the velocity and turbulent intensity in the self-preservation region, LDV (TSI 2550) measurement is undertaken. And next, the camera calibration for two cameras, B/W (SONY AVC-D7) and Color camera (3CCD SONY XC-009, shutter speed 1/250 sec), is done for the measurement of three dimesional position of those particles in the jet flow. After finishing the calibration work for two cameras, the main experiment is worked out in which the visualized images are recorded onto the optical disc (SONY, LVR-5000) through the TV color camera. At this time, the image from B/W camera is also recorded onto the same kind of another disc synchronized with a controller designed by the author. And then, the color-to-temperature calibration is achieved. After the color images recorded in the laser disc are digitized to 256 levels in the image processor (NEXUS 6400) and are processed, r, g, and b are obtained. The data from this calibration are used for temperature measurement of the jet. The host computer controls TV camera operations, handles GPIB communication and performs data acquisition and analysis.

The purpose of the camera calibration for two cameras is to measure three dimensional positions of those particles in the jet flow. During the course of camera calibration, the traverse system located on the upper part of the jet tank, is traversed three-dimensionally to make the three-dimensional index marks. During the calibration experiment for camera, the whole images taken by B/W camera and color camera are stored on to LVR (SONY 3000A) for post processing. After finishing the calibration work for two cameras, the main experiment is worked out in which the visualized images are recorded onto the optical disc (SONY, LVR-5000) through the TV B/W and color cameras. At this time, the image from B/W camera is also recorded onto the same kind of another disc synchronized by a controller designed by the author. For visualization, a halogen cold light (150W) is used to illuminate the flow field. During the experiment, three thermocouples were inserted in the flow field without disturbing the measuring area flow in order to confirm the mean temperature of the water in the water tank. After taken the images on the main experiment, an experiment for the color-to-temperature is done. During the experiment of color-to-temperature calibration, the whole experimental condition is maintained without changing any experimental factor used up to now. The data obtained in the color-to-temperature calibration are used for the temperature measurement, in which the neural network explained in the third section of this paper series is applied to get the temperature corresponding the color data r, g, and b. Finishing the above experiments, post processing

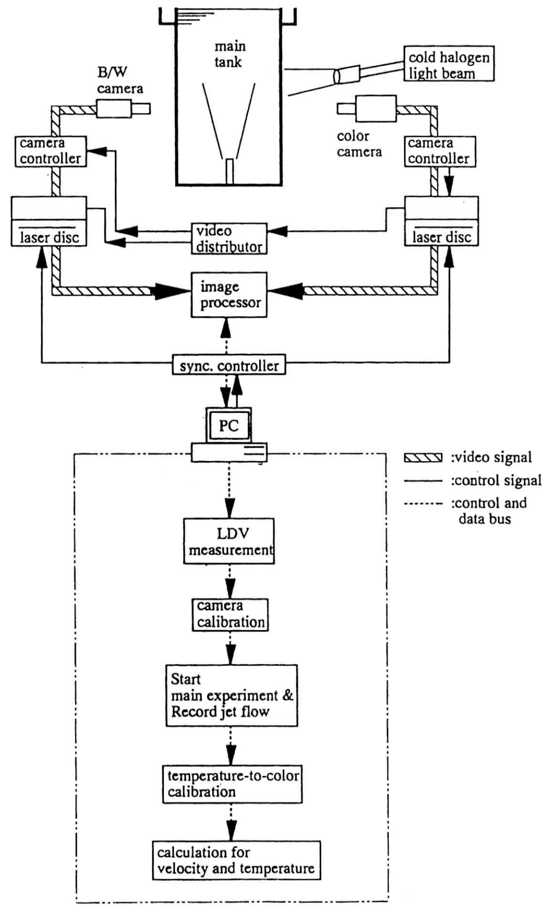


Fig. 2 Procedure of overall experiment

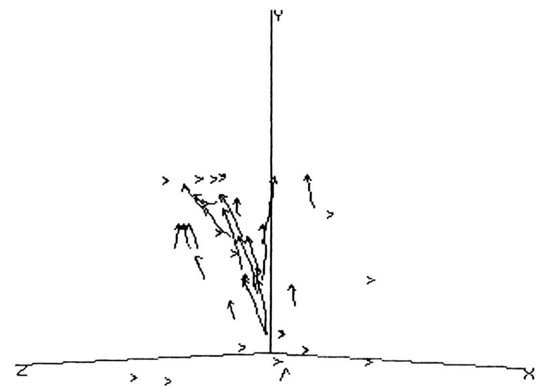


Fig. 3 Three dimensional temperature and velocity

including, calculation of camera parameters, getting the color-to-temperature characteristic, and color image processing for the main experimental images stored in the LVR is done.

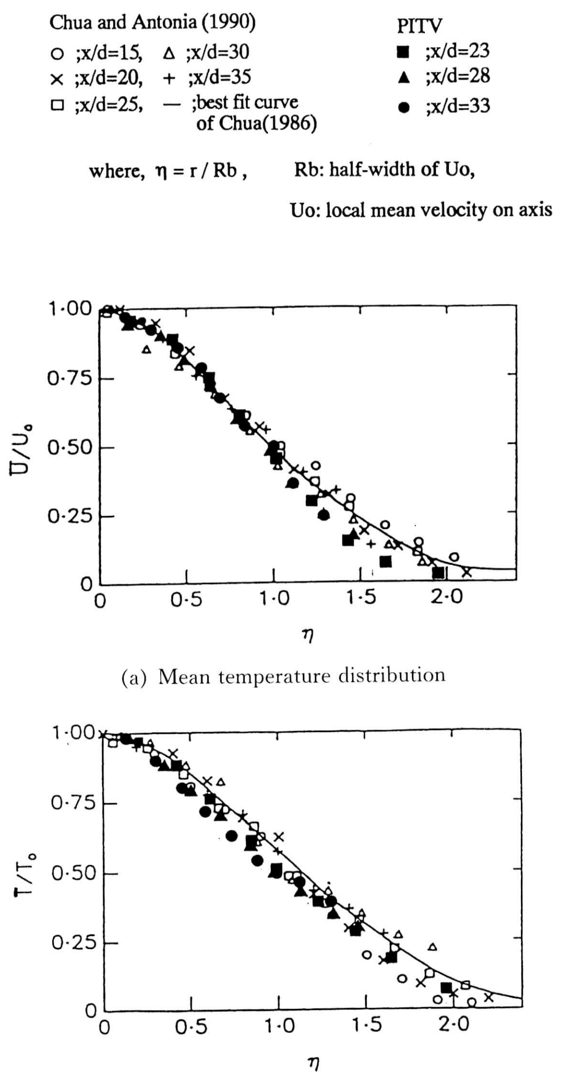
In order to measure three dimensional velocity, instantaneous particle positions are extracted by thresholding the sets of eight consecutive processing images[4]. The gravity centers and colors of particles are extracted by a digital color image processing and the two-dimensional trajectories of two camera images are used for fast stereo-pair matching. And after this three-dimensional temperature and velocity are calculated by using the data obtained in the two calibrations of camera position and color-to-temperature.

By the measurement method applying the neural network and stereo-pair matching method, the following results could be obtained. Figure 3 shows an example of three-dimensional temperature and velocity tracking, in which the letters representing temperature are not typed for convenient views. In order to evaluate mean property of the jet flow, sets of 800 images are processed and about 50000 velocity vectors are detected in the same way. Since the rare data obtained through the color image processing suggested don't have understandable information for temperature and velocity, to quantify the temperature and the velocity the interpolation process[4] is adopted. The interpolated data are compared with the results by Chua[5] as shown on the figures 4(a) and 4(b). The black points are the results through this technique. From these figures, it can be said that the similarity in the self-preservation region is relatively high ensuring this method is applicable to the simultaneous measurement of temperature and velocity of a thermal fluid flow.

For the confirmation of the validity of this technique, the uncertainty analysis based on ANSI/ASME[6] had been done. The uncertainties for the temperature measurement is undertaken through the neural network applied in this study as in the similar manner[7]. The uncertainties for the temperature measurement was ±0.12°C in 95 percent reliability. The uncertainties for the velocity measurement in this study is based on the analysis method done by Nishino[8]. The uncertainties for the velocity components, u, v, and w measured by this technique were ±6.2 mm/sec, ±4.8 mm/sec, and ±4.5 mm/sec, respectively in 95 percent reliability.

Conclusions

This paper has aimed to develop a new technique that measures three-dimensional simultaneous temperature and velocity of a thermal fluid flow adopting a new color image processing technique in which a neural network has been



(a) Mean temperature distribution

(b) Mean temperature distribution

Fig. 4　Experimental results

adopted for color tracking of the liquid crystal particle. After overcoming the two problems already dealt in the previous two sections, the optical characteristics and the response time characteristic, a three-dimensional simultaneous measurement for temperature and velocity of the vertical buoyant jet has been worked out. By using the non-metric B/W and color cameras, applying the stereo photogrammetry and digital color image processing technique, it was verified that this technique was able to measure simultaneous spatial temperature and velocity of the vertical buoyant jet by comparing the results from this technique with those of other researchers in the self-preservation region.

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