§26. Three-dimensional Observation System for Pellet Ablation in LHD Plasmas

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In order to investigate an ablation of a solid hydrogen pellet, which is injected into high temperature plasmas with high speed (~1 km/s) for the plasma refueling, three-dimensional observation system of a fast camera has been developed. A stereo method has been employed to obtain the three-dimensional information of the pellet ablation. A pair of the stereo images, which has been taken from different location, has been focused onto single fast camera by using bifurcated imaging fiber scope, to ensure that the simultaneity of the both images. The projection matrix, which is used for a stereo reconstruction, is calibrated by taking images of a model plane of known coordinates from the actual camera positions.

Accuracy of the stereoscopic measurement is examined by the model plane, which was used at the camera calibration. Fig. 1 shows measuring accuracy of Z axis, namely, depth direction. The horizontal axis and vertical axis indicate the actual Z value of the model plane and the stereo reconstructed Z value, respectively. The stereo reconstructed Z value show good agreement with the actual Z value within the range of the error. The thick error bars indicate maximum and minimum stereo reconstructed Z value for a model plane, which is put at Z. The Z error is about ±30 mm that is ±2 % for the Z coordinate as shown by thin alternate long and short dash lines. The thin error bars indicate the range of scatter in reconstruction, when a stereo matching has ±3 pixel error. The reconstructed X-Y coordinates have a similar accuracy to the Z coordinate. It is confirmed that the stereo reconstruction provide the good estimation of the spatial coordinates with linearity.

In order to demonstrate the usefulness of this measurement, an ablation behavior of a pellet, which is injected into the LHD plasmas, has been analyzed. Fig. 2 shows temporal change of a pellet ablation light intensity, which is measured by a photo-diode with H_α filter. Assuming that the initial pellet velocity maintains during ablation, the pellet position can be predicted as a broken line in figure. The stereo observation has been carried out with

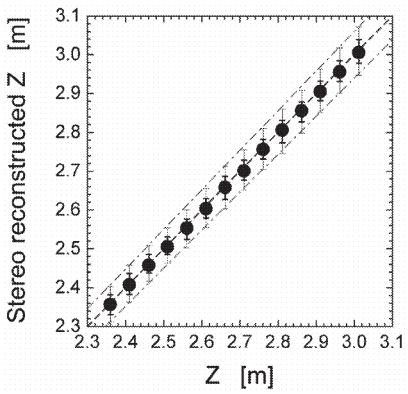

Fig. 1 Stereo reconstructed Z coordinate versus actual position of the model plane. Thin alternate long and short dash lines indicate ±2 % error.

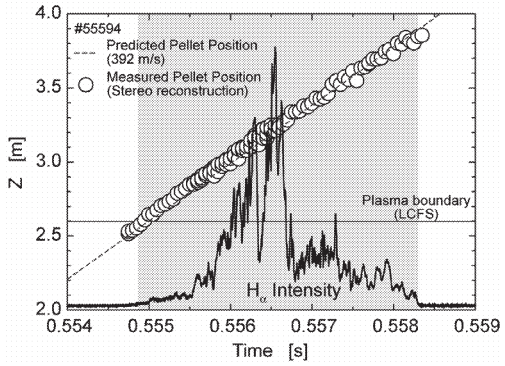

Fig. 2 Temporal change of the predicted and stereo reconstructed pellet position and H_α intensity.

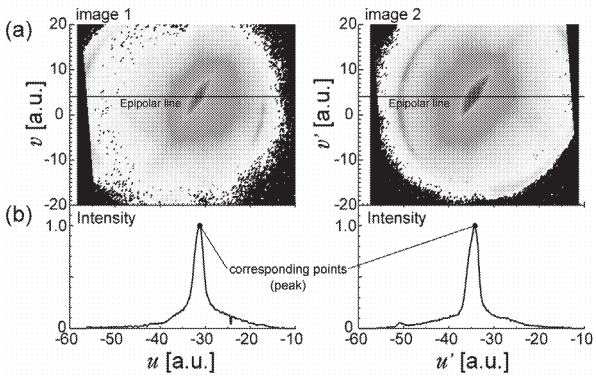

Fig. 3 (a) Typical stereo pair of the ablating pellet and (b) the emission intensity distribution along the epipolar lines.

sampling rate of 20,000 images per second and exposure time of 4 μs. In this experiments, a life time of the pellet is relatively long (> 3 ms) because of low temperature target plasma ($T_e(0)$= 0.7 keV) and about 70 pairs of the stereo images are obtained during ablation. Fig. 3(a) shows the stereo pair of the typical pellet ablatant. An epipolar line is parallel to horizontal axis in both images. The emission intensity distribution along the epipolar lines is shown in fig. 3(b). Stereo matching has been carried out by a feature-based stereo matching procedure, i.e. the corresponding points in each images are defined by the brightest points along the epipolar lines. The pellet position, which is measured by the stereo observation, is plotted in the fig. 2 by the open circles. The pellet position, which is reconstructed by the stereo analysis, showed good agreement with the predicted pellet position. In other words, it has been confirmed by this method that the initial velocity of a pellet maintains during ablation in hot plasma. At the same time, we can observe structure of the ablating pellet on X-Y plane by the images.

We acquired ability to obtain three-dimensional information of the obvious corresponding points such as emission peak. In respect of the subject for a further study, full three-dimensional reconstruction using an area-based stereo matching procedure is required to perform more detail observation. In addition, multi-point simultaneous observation is also useful to reduce blind spot and to perform stable stereo analysis