

Automatic video tracking and first analysis of dust particles trajectories from all tungsten ASDEX Upgrade

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Introduction: Production and accumulation of dust may cause serious safety and operational problems expected in future fusion devices as ITER. There, dust is considered as a negative factor due to its radioactivity (tritium and activation products), toxicity (beryllium) and chemical reactivity with steam and air (volatile compound formation, explosion). Also operational issues are associated with dust such as radiation energy losses in core and edge plasma and the risk of dust-triggered disruptions. In this perspective, it is necessary to better understand the impact of dust on the plasma performance and operation. For that purpose, discharge conditions have to be linked to dust production and migration via statistical analysis of individual dust particle characteristics and trajectories. A first analysis of dust particles trajectories from fast camera measurements in all tungsten ASDEX Upgrade (AUG) tokamak was then performed. This study requires the processing of a huge amount of video data (more than 9 TB) accumulated over three years under various discharge conditions in the AUG database. For that reason, an algorithm allowing detecting particles and extracting their trajectories automatically directly from camera measurements has been developed. Its reliability is preliminarily assessed using dedicated simulations and experiments.

Experimental setup for test experiment

For testing and checking the reliability of the tracking applied to dust particles, macroscopic (tens of μm and larger) carbon dust particles were generated in a capacitive coupled RF parallel plate reactor working at frequency 13.56 MHz, with upper electrode being biased and lower one grounded (cf. Fig. 1). Plasma was initiated in a mix of argon and acetylene (C_2H_2). The motion of dust particles was recorded by a fast camera FASTCAM SA1.1 by *Photron Ltd*. Image recording is provided by a 12 bits monochrome CMOS sensor, with one mega pixels at up to 5400 fps. To improve the spatial resolution, an external objective Nikon Micro-

NIKKOR 105 mm was mounted providing a resolution of 20 μm per pixel.

Since the particle size depends on operating parameters, they had to be well chosen to achieve satisfying conditions for our experiments. For this purpose, RF power ranges from 10 W to 20 W, and the pressure was set to ~ 10 Pa. This range of values allows obtaining dust particles with sufficient size to be observable by fast imaging camera. The frame rate providing the clearest image was figured out to be 1000 fps. For this frame rate, the particle mean displacement between two frames is about 1 pixel, which is well suited for tracking.

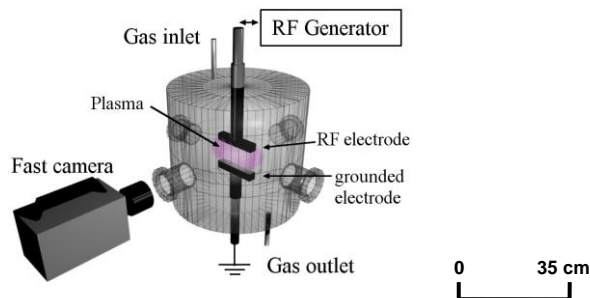


Fig. 1: General scheme of experimental setup

Validation of the tracking algorithm:

Direct camera measurements performed in our parallel plate reactor shows complex motions of dust according to operating parameters (cathode bias voltage via RF power, pressure, etc...). For example, dust trajectories observed in presence and in absence of gas inlet flux show strong deviations, as illustrated in Fig.2. When there is no gas inlet, particles generally grow at a given place and then fall down due to gravity. In the opposite case, trajectories of lots of particles exhibit clear tendency for particles to move in the horizontal direction.

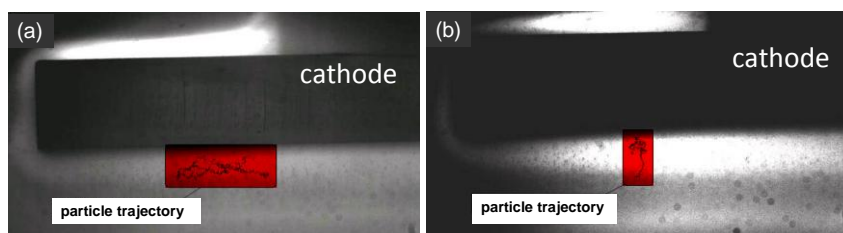


Fig. 2: Comparison of particle trajectories in presence (a) and absence (b) of gas inlet

Due to high particle density, strong luminosity fluctuations and experimental noise, the requirements for particle tracking in this experiment are very similar to the most challenging ones in tokamaks, such as e.g. during ELMs and after disruptions. In order to assess the efficiency of the tracking procedure, trajectories have to be known *a priori*. As a first step of the validation, virtual dust particles with known trajectories were simulated in a finite size box. The perfectly known trajectories were confronted to the ones found with the tracking procedure. Results for 1000 realizations and for two sets of velocity distributions are given in

Table 1. For a random velocity distribution, 30% of the 60 particles are perfectly tracked over the 500 frames of the simulation. On average, particles are correctly tracked during 75% of their trajectory, i.e. 375 consecutive frames. Mistracking is caused by recombination of different particle trajectories due to occlusions, or to particle jumping more than the expected maximal displacement (set to 5 px between 2 consecutive frames). However, in the case of a forced oscillation in one given direction (collective motion), half of trajectories are perfectly extracted and the global accuracy is about 85%. These results indicate that for dust particles with well-defined trajectories in at least one direction, the procedure is more efficient.

Velocity distribution	Ratio of perfect trajectories	Global accuracy	Number of occlusions	Number of particle jumps
Random	30%	75%	608	127
Random (x,y) + z oscillations	50%	85%	56	57

Table 1: Comparison between known and reconstructed trajectories obtained with the tracking procedure.

60 particles in a 60×60×60 box were considered for 500 frames.

In order to test and validate experimentally the efficiency of the complete detection and tracking efficiency of dust, sheath perturbations were applied to induce dust collective response. By correlating automatically found trajectories with sheath light fluctuations, it was shown that 2/3 of detected particles existing for more than 50 frames were well-tracked. This demonstrates the satisfying reliability of the tracking algorithm even under challenging conditions (i.e. very high particle density and strong intensity fluctuations).

Application to dust particle tracking in ASDEX Upgrade video data

Tracking algorithm is then used to process video data from AUG database. Videos were recorded by a fast 14 bit depth resolution Phantom camera with a typical frame rate of 10000 fps. First results about tracking efficiency in the particular case of a disruption are presented. Two video sequences recorded at different conditions of luminescence and experimental noise were investigated and show a varying efficiency as seen in Fig.3. In the first case (shot AUG#23246), particles are very bright compared to an almost dark background just after the disruption. Low experimental noise, low particle velocities and linear trajectories are also characteristic of this movie where tracking extracted all particles trajectories (yellow circles) up to 2000 consecutive frames with a very good efficiency. Stationary events such as hot spots (red circles) are also well detected. In the second case (shot AUG#23732) characterized by a constant luminous background after the disruption, strong experimental noise, high

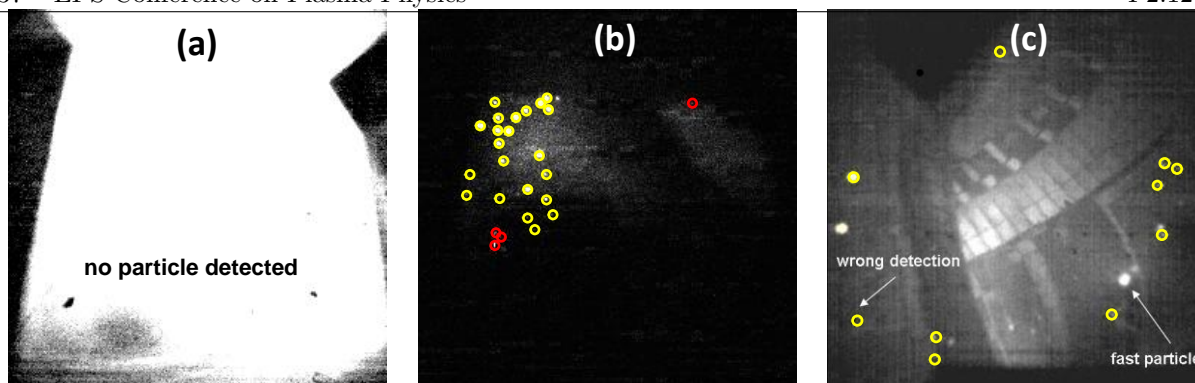


Fig.3: Dust particles (yellow circles) and hot spots (red circles) tracked a) during the disruption; b) with low intensity background after the disruption; c) with constant luminosity background after the disruption particle velocities and random trajectories, the procedure systematically overestimates the real number of short dust events (less than 10 frames trajectories). Moreover, constant background luminosity causes misdetection and high-speed particles are not well tracked. However, the tracking algorithm extracts with a high accuracy long trajectories (>50 frames) in both cases, allowing the statistical analysis of long trajectories. Note that the hybrid global/local thresholding technique that we use [1] is not confused by the disruption itself: no misdetection occurs during this event.

Conclusion and outlook

An algorithm allowing extracting automatically dust trajectories from camera measurements in various discharges conditions has been developed and tested. Although the procedure is still under constant improvement, long trajectories are already obtained with a good reliability, even under extreme conditions, such as disruptions. The automatic procedure is currently used to analyze AUG data. Future work will focus on linking particles density, dust production and migration sites to different discharges conditions through the statistical analysis of individual trajectories. Further developments of our detection and tracking algorithm are still needed in order to guarantee the highest reliability independent of the plasma conditions. Stereoscopic measurements, allowing reconstruction of 3D particles trajectories will be started in autumn 2010.

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References

[1] N. Endstrasser *et al.*, 19th Int. Conf. on Plasma Surface Interaction, P2-85, May 24-28 2010, San Diego, USA