

A Review on Dust Particle Image Analysis in Dusty Plasma

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Abstract

Plasma is gas of charged and neutral particles that exhibit collective behaviour. Studies of dusty plasma associated phenomena are known to have applications in many astrophysical environments, laboratory environments and in industrial plasma systems. Presence of dust particles in plasma invariably changes their behaviour and become dominant in terms of energy and momentum transport. The most prominent of these techniques are the Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV). Dust structures and motion of dust particles in plasma are studied in the laboratory by making optical measurements using the scattering of laser light. Taking a sequence of image is one of the most important methods of diagnosing dusty plasma. Understanding the motion of the dust particles is also very important from the point of view of controlled nuclear fusion. Presence of dust in controlled nuclear fusion reactor is not desired and large amount of dust is expected to be produced in thermonuclear reactor; hence understanding the behaviour of dust particles in plasma and its efficient removal from the reactor will be useful from the point of view of controlled nuclear fusion. It holds the promise of potentially limitless and clean energy. This paper undertakes a comprehensive review of the various techniques discussed in these research papers and attempts to qualify them based on their approach, accuracy of results, ease of implementation and critical shortcomings.

Keywords: Dusty Plasma, Nuclear Fusion, PIV, PTV

1. Introduction

The rapid human development across the globe, the rapid increase of energy is a very basic need and a fundamental requirement to survive in the present time. In the face of rapid reduction of natural resources, this need must be fulfilled via other sources like nuclear and renewable sources. Nuclear energy holds the promise of limitless energy potential as it has a very high energy density. The two basic principle of nuclear energy namely nuclear fusion and nuclear fission are at the forefront of this extremely large nuclear potential. Nuclear fission although relatively easy to initiate and sustain has the drawback of being inefficient and dirty in that it produces a lot of

undesirable and potentially harmful waste product/s as a part of the fission process. Nuclear fusion on the other hand is clean and efficient with no harmful by-products. The fundamental criterion for initiating a nuclear fusion reaction is the presence of very high temperatures of the order of millions of Kelvin's. No element discovered today can withstand such high temperatures for long period of time. Hence in order to deal with such high temperature reactants and control and co-ordinate their actions a non-physical means of containment is required. Magnetic fields are used to control the plasma, in order to address these issues and make nuclear fusion a more feasible option for power generation. A is a kind of device⁶ which confines plasma in the shape of a torus. Using a lateral

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and orthogonal magnetic field for confinement of the plasma, non-contact confinement of tokamak the plasma is achieved. Complex geometry of magnets is laid around the tokamak in order to produce very strong magnetic fields. Nuclear fusion inside the plasma uses deuterium (an isotope of hydrogen), which is widely available in sea water and tritium that can be extracted from lithium, which is available in earth crust. It has small effect on environment as compare to other available energy sources.

When a solid material is heated up it turns into liquid. Further, when a liquid is heated up it turns into gas and finally when gas is heated up it turns into ionized gas or plasma. Dusty plasma is a mixture of highly charged micro spheres, electrons and ions². Presence of dust particles in plasma invariably changes their behaviour. Dust particles in general lead to decrease in the plasma temperature, induce unwarranted turbulence and decrease plasma density. An effective dust particles analysis will partially resolve the reason of temperature decrease from the tokamak, so that nuclear fusion can be sustained for a longer duration. The data extracted from PIV can be used for the determination of dust temperature, determination of distribution function, calculation of time period of rotation, plotting of velocity map with scale and generation of 2D colour map showing angular velocity and linear velocity. A lot of effort has been made to create a managed and sustainable plasma environment by making meaningful observations of these dust particles¹. Researchers are trying to maintain temperature and density of plasma inside the tokamak device. Dust structures and motion of dust particles in plasma are studied in the laboratory by making optical measurements using the scattering of laser light from the dust particles.

Some of the applications of plasma are the following: Plasma display, an electronic display technology commonly used for televisions. It has advantages like: high resolution, less price, slim in size etc. over LCD, CRT. Plasma torch, industrial equipment used to cut Steel, Aluminium and other metals. Plasma spraying is a technique used to coat structural materials that helps to protect against high temperature. Plasma arc waste disposal is used commercially as a form of waste treatment. Plasma antenna can be used for both transmission and reception. Plasma arc is used for joining of metals. It can

fuse two metals with or without filler metal. Plasma lamp is a lamp electrified by radio frequency power. This paper discussed the dust particles analysis through PIV, PTV and other techniques to study the nature and behaviour in dusty plasma.

2. Basic Concepts

Dust particles have been found in plasma through a sheet of laser light that helps to light up these particles and determine their catching position². The dust particles image is analysed using PIV, PTV and openPIV spatial and temporal analysis techniques. These techniques are independent, open source and supported by Mat lab.

2.1 PIV

It is an experimental technique. It has been developed over the past decade by the fluid mechanics community. It can obtain data from a densely dust particle image, where single dust particle cannot be identified. The signal-to-noise ratio value can be used to reconstruct velocity of dust particle. It has two types: peak to mean and peak to second peak.

2.2 PTV

It is an experimental technique and helps to track the individual particle direction and magnitude of the particle flow. It is used when the dust particles are well defined and the plasma field is thin seeded. PIV data can be used for validation technique for PTV data.

2.3 OpenPIV Spatial & Temporal Analysis Toolbox

It streamlines the post-processing of the PIV data obtained using OpenPIV or other software. It can measure the velocity of fluid flows in gases and liquids. PIV data can be used to calculate contour quantity like: linear velocity, vortices of dust particles. Time period of rotation of dust particles can be analysed by this toolbox. It has properties of making animation and movie of these dust particles. Contour properties like: flood, colour line, flood and line and black line of this toolbox provides to visualise the dust particle in different perspective.

3. General Architecture for Dust Particle Image Analysis

Figure 1 shows the System Architecture for Image Analysis of Dust Particle

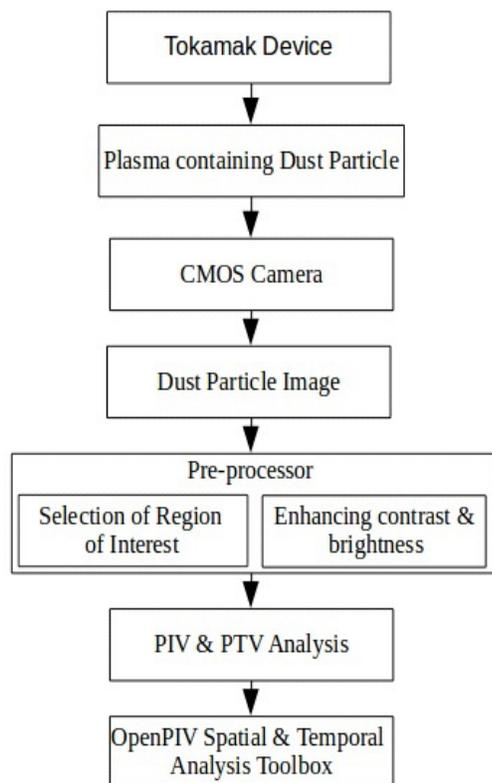


Figure 1. System Architecture for Image Analysis of Dust Particle.

4. Dust Particle Image Analysis Work

There are several particle image velocimetry analyses available in the dusty plasma environment.

- Edward Thomas² suggested that PIV is a powerful experimental tool and can measure two-dimensional velocity profiles of dust particles accurately. Estimation of average forces can be obtained by the sequence of velocity profiles of dust particles. It also suggested that two-dimensional speed profiles, velocity shear and gradients can be calculated accurately by post processor of the velocity profiles. Direct current discharge technique has limited amount of information about dust particles in dusty plasma. So, it is difficult

to understand the physics of dust particle movement.

- C.M. Boesse et al.¹ proposed that digital imaging and analysis system that helps to minimize the loss of data in all processing steps. Data obtained from this analysis is quick and efficient than any other method. Dust particle analysis has been greatly improved under digital imaging. It uses both PIV and PTV techniques. This method minimizes the loss of data in all stages of acquisition and processing.
- Gary S. Selwyn³ proposed PIV analysis using Laser Light Scattering (LLS) technique. LLS uses helium-neon lasers for dust particle analysis in plasma and other plasma related applications. It addresses the scientific issues, such as the formation, growth charge, and transport of dust particle that highlight the different nature of particle. This method has greatly improved dust particle analysis in plasma.
- V E Fortov et al.⁴ analysed the thermodynamic and kinetic properties of displacement. It is also possible to analyse the defects in dust grid. Investigation of phase transitions in systems of symmetric and asymmetric dust particles provides useful information about critical incident and self-organization processes, in particular, about the possibilities of natural formation of ordered dusty-plasma structures in the universe.
- Cheng-Ran Du et al.⁵ suggested new features of the recently discovered effect of upstream extra particle directed towards 2D complex plasma crystals. The heat transfer was discussed as an example by particle channelling for transport incident. This model does not explain the particle channelling in liquid complex plasma.
- Andre Meltzer et al.⁶ applied transfer entropy to analyse the behaviour of charged dust particle under the influence of an ion focus in dusty plasma. Transfer entropy data is transported from the upper particle in an ion flow to the lower. An ion flow in an envelope can be explained by the ion focus. Entropy transfer is one of the reliable measures for information asymmetry. This technique does not able to detect the asymmetry in the particle communication from a numerical, probabilistic measure.
- Myriad tracking of dust particle⁹ has extended Kalman based filter to study very tiny layer of dust particles accurately using less resource intensive technique. It uses Kalman filter based algorithm due to sheer size of the matrix involved. This was solved by dividing the myriad targets into manageable multi target subsets. The method is extended by Bayesian inference filter.

- J. Goree, et al.⁸ suggested moment-method image analysis that provides the micro spheres' position and velocities in strongly coupled dusty plasma. The data in the dust particle pattern are converted into the continuous pattern by storing, providing hydrodynamic quantities that are recorded as a framework. This method is based on the diagnostic methods for determining transport coefficients in strongly coupled dusty plasma.
- Neil P. Oxtoby et al.¹⁴ proposed crystal like phase of dusty plasma was tested by Extended Kalman Filter algorithm. It tracks a target dust particle based on positional data of the neighbours. It provides a standard for measuring the performance of more advanced algorithms that will be necessary for treating more complex dust particles. This analysis technique will degrade the further dusty plasma deviates from a crystal-like state.
- B. A. Klumov et al.¹⁰ suggested the behaviour of a group of charged dust particles whose interaction with each other is described by the Yukawa potential has been investigated by the molecular dynamics method. The parameters of the dust particles and complex plasma were taken to be close to the respective experimental values.
- R. L. Merlino et al.¹¹ suggested that the dust audible mode was observed in dusty plasma. It has been found that the charged particles were raised by an electric field. It was examined by a current driven electrostatic dust uncertainty in collision plasma using a four-fluid model. This technique does not explain the importance of dust particles effect in magnetic field, because of choosing the realistic parameters.
- J. Winter et al.¹² suggested that particles will often interact with tokamak device wall component and emits magnetic and electric forces which float them. Exhausting and thermal overloading of wall components appear to be the most important mechanisms for dust particle formation. The formation of dust particles could be one of the reasons of emission spectroscopy that guides to material loss. The well-investigated mechanism in reactive process plasma identified that the size and shape of the smallest particles are consistent.

5. Observation

The following Table 1 defines the comparison, advantages and disadvantages over different PIV models.

Table 1. Comparison for different dust particle analysis and its advantage/Disadvantage

S. No.	Dust Particle Analysis	Type of Technique	Advantages/Disadvantage
1	Digital image and its particle analysis in dusty plasma	Both PIV and PTV	It helps to reduce computation time. It has ability to calculate accurate particle velocities whereas it is very difficult to answer individual particle velocity.
2	Measurement of two-dimensional velocity in dusty plasma	PIV and Spatial Toolbox	Two-dimensional velocity profile in dusty plasma can be accurately measured.
3	PIV measurement of indoor airflow ⁷	PIV and Spatial Toolbox	1. The data obtained from full scale models are the most realistic and reliable. 2. Small scale models may suffer from scaling problem and not represent the real condition.
4	Myriad tracking of dust particles	PIV and Extended Kalman Filter	It has relatively low RMS error.
5	Tracking interacting dust particle	PIV and Extended Kalman Filter	It improved the precision as well as significantly reducing errors due to pixel locking.
6	PIV measurement in complex geometries ¹³	Both PIV, PTV and rapid prototyping	1. The dust particles details help to removal of pollution and drug particles from nose space. 2. Inability to fabricate accurate, transparent replicate model.
7	Digital optical and analysis system	Both PIV and PTV	At different processing stage it helps to minimize the loss of data. Analysis of dust particle is also greatly improved.

6. Conclusion

The dusty plasma is a fast growing research field in physics since past decade. In this review, the authors

suggest the most important experimental and theoretical results related to plasma analysis. There are many real time applications of plasma like plasma torch, plasma display, plasma arc waste disposal etc. Still some problems have to be addressed like generating energy from the nuclear fusion, removal of dust particles when making computer chips by plasma assisted technology. A deep understanding of physical processes in gas-discharge dusty plasma is required to address these problems. Experiments and researches are going on all over the world to find out the solution of dust particles so that nuclear fusion inside plasma sustains for longer duration so that it will be producing enormous amount of energy at the cheapest rates and relatively less effect on environment.

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