

Advances in fast 2D camera data handling and analysis on NSTX

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ABSTRACT

The use of fast 2D cameras on NSTX continues to grow. There are 6 cameras with the capability of taking up to 1–2 gigabytes (GBs) of data apiece during each plasma shot on the National Spherical Torus Experiment (NSTX). Efficient storage and retrieval of this data remains a challenge. Performance comparisons are presented for reading data stored in MDSplus, using both compressed data and segmented records, and direct access I/O with different read sizes. Encouragingly, fast 2D camera data provides considerable insight into plasma complexities, such as small-scale turbulence and particle transport. The last part of this paper is an example of more recent uses: dual cameras looking at the same region of the plasma from different angles, which can provide trajectories of incandescent particles in 3D. A laboratory simulation of the 3D trajectories is presented, as well as corresponding data from NSTX plasma where glowing dust particles can be followed.

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1. Introduction

The National Spherical Torus Experiment (NSTX) is a medium-sized, magnetically confined, fusion experiment (plasma major radius up to 85 cm, minor radius up to 68 cm) at the Princeton Plasma Physics Laboratory (PPPL) [1]. NSTX is particularly well suited to studying particle confinement, turbulence, plasma facing component conditions, and the internal characteristics of plasmas, due in large part to the open geometry of NSTX which allows good diagnostic access. Fast 2D cameras play important roles in these studies. During an experimental discharge, or “shot,” a plasma is sustained for approximately 1 s and about 1 GB of scalar and time-varying signal data is acquired from numerous plasma control subsystems as well as over 50 individual diagnostics. An additional 3–4 GBs are archived from fast 2D cameras. Most signal data is transferred to and stored on centralized data servers in MDSplus [2–4] and is available to display programs and automatic analysis tasks anywhere between 10 s and 3 min after the discharge. Our data stored in MDSplus is easy to locate and read; we have not yet been as consistent in storing our fast camera data. A typical NSTX run day produces about 40 discharges. NSTX runs for between 60 and 80 days a year. Eleven terabytes of raw and analyzed NSTX (compressed) data currently reside on centralized disks.

2. Overview of fast 2D camera applications on NSTX

Fast 2D cameras (see Table 1) are used to look at a variety of different phenomena inside the vacuum vessel of NSTX. Recording rapidly varying features within plasmas provide insight into a host of processes including plasma-wall interactions, impurity production and transport, divertor performance, etc. The evolution of edge localized modes (ELMs) and MARFES has been recorded at over 100,000 frames/s [5]. Two Phantom cameras [6] have been used to look at heat deposition and macroscopic dust creation in the diverter region of NSTX and a number of divertor detachment scenarios [7]. These latter phenomena require the application of narrow band interference filters to view specific elements in various excited states. The color Miro[®] camera can be used as a good indicator of a number of excited states. Turbulent structures in the plasma edge have been visualized using deuterium gas puffs recorded at 250,000 frames/s allowing characterizations that can be compared with theoretical models of turbulent flow [8]. 3D particle trajectories of macroscopic incandescent dust particles have been obtained for NSTX plasmas by using two cameras with overlapping fields of view [9]. Recent work using 2 fast cameras to track dust particles is presented below.

3. Data handling performance comparisons

In the NSTX Control Room, animations from the fast 2D color Miro[®] camera are displayed on a large screen Display Wall, and several more people might be playing the animations at their workstations. Moving large amounts of data from storage to the various

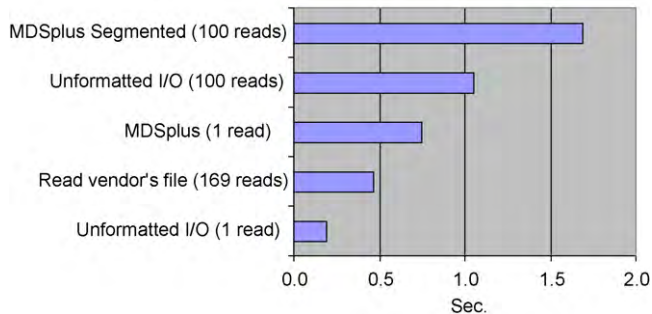
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Table 1
Characteristics of fast 2D cameras used on NSTX.

Camera type	Typical MB/shot	Max MB/shot	Min rate (kHz)	Min rate resol.	Max rate (kHz)	Max rate resol.	Bits
Phantom 7.3 (2)	350	3500	6.6	800 × 600	190	32 × 32	14
Phantom 7.1	350	3500	4.8	800 × 600	150	32 × 32	12
Photron Fastcam	750	1500	2.0	1024 × 1024	120	128 × 16	10
Miro2	50	2000	1.2	800 × 600	111	32 × 16	12
Phantom 4.2	1000	3500	2.1	512 × 512	90	32 × 32	8
S.B. Focalplane	50	64	1.6	128 × 128	6	96 × 32	14

Table 2
Times to read 100MB of data from a SAN connected via 2 gigabit/s fibre channel.

Time to Read 100MB of Data from SAN



workstations can slow down the network performance to the point where the animations cannot be played at useful speeds. Using widely known standards such as MDSplus is an important consideration when selecting data-handling solutions, however, overall performance can also influence design decisions.

Table 2 shows the time to read 100 MB in our typical configuration (on an 8-CPU 2.6 GHz Linux computer with 10 GBs of memory accessing SAN disks connected via fibre channel); there were no TCP/IP transfers used in these tests. This would only be 1/3 to 1/10 of the data from a typical fast 2D camera for a discharge on NSTX. All of these tests were made from IDL [10]. The number of “reads” indicated is actually the number of calls to read subroutines, and, generally, not the actual number of I/O requests to the disk. The advantage of using MDSplus segmented records or something like Open-source Project for a Network Data Access Protocol (OPeNDAP) [11], is that fractions of large data sets can be read, rather having to wait for huge data sets to be transferred. This is also the case with direct I/O, as used in the custom-written code we use for accessing “vendor’s files,” which are “Cine” files in the case of Phantom cameras. Direct access also occurs when individual frames are

stored as image files. The substantial drawback with these custom solutions is that every format requires different access methods and the files can be in random locations. Perhaps the performance of MDSplus can be enhanced so users can benefit from both convenience and speed. Some preliminary tests using the OPeNDAP protocol at another site took 160 s to read 100 MB on a local disk. More work needs to be done to make these tests more consistent, or to understand this difference.

The management of fast 2D camera data for the 2009 NSTX campaign varied among cameras. Data for the Photron Fastcam was stored in MDSplus [2], in its own tree, but for the other cameras only metadata and a waveform of total intensity vs. time was stored in MDSplus. Segmented Records, implemented in MDSplus in the last few years, were used when writing large camera data sets into MDSplus. Raw camera data files (“Cine” files for the Phantom cameras [6]) stayed on the host PCs as long as there was room, and were sometimes manually saved to external hard disks or to DVDs. The lab-wide Netbackup system backed up data on the PCs over night. Sometimes between shots and sometimes on demand, the Fast Camera data files were copied to Sun Microsystems’ ZFS™ disks on a SAN connected via fibre channel. ZFS file systems can be expanded a disk at a time beyond any practical limit (up to 16 Exbibytes). Automatic, transparent compression can be enabled on ZFS file systems to reduce the size of typical Cine files by factors of 2–3, although writing these files in the compressed format takes about 40% longer and reading them takes about 10% longer in our environment. Our network route for moving camera data to centralized disks had segments with only 100 Megabit/s bandwidth. With an increase in camera data expected for 2010, we are planning to have at least 1 gigabit/s throughout the route. By retaining the vendor’s file format for the camera data, the vendor-supplied Phantom Camera Control Software [6] can be used to enhance, playback, and convert the Cine files. C# routines were also provided by the vendor to read the Cine files. IDL and C routines for reading Cine files were written at PPPL (available upon request). A locally written IDL program called FCplayer is used for browsing and enhancing images, making mpegs, etc.

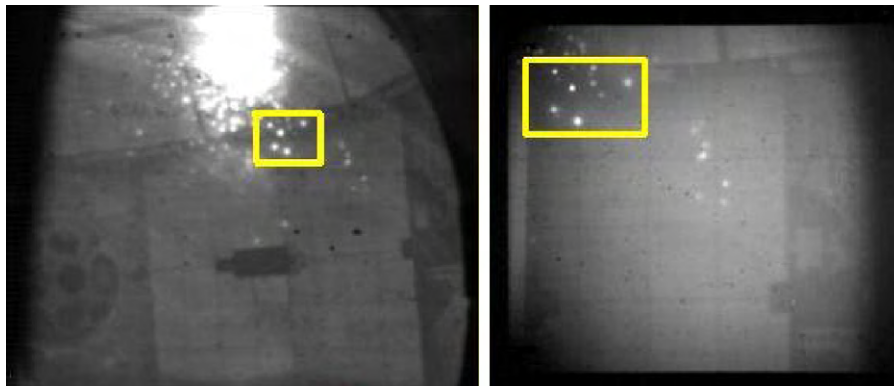


Fig. 1. Forty micron diameter lithium dust being dropped into NSTX. The box encloses the same particles in views from two different fast cameras. The cameras are operated at up to 20,000 frames/s and dust particle velocities of up to 100 m/s have been observed.

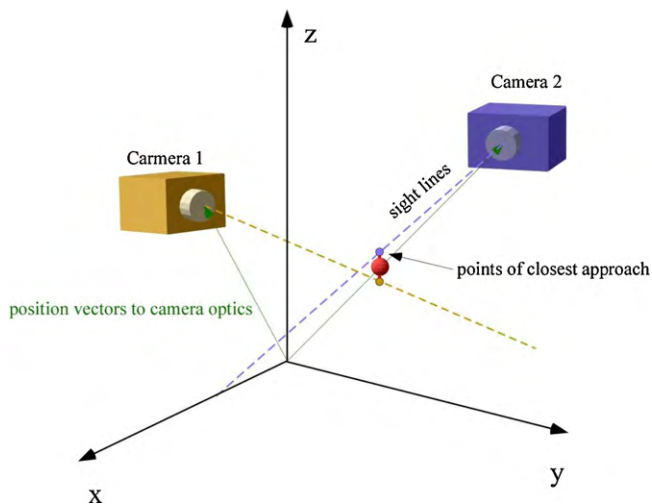


Fig. 2. Reconstructed trajectories of visible particles in NSTX. Projections of tracks from above are shown in gray on the X–Y plane.

4. Particle trajectory tracking in three dimensions

The rest of this paper describes an example of using 2 fast 2D cameras for characterizing a plasma. Tracking incandescent “dust” in plasmas can help analyze plasma behavior, and determine the transport of pre-characterized injected material. The lithium dust particles shown in Fig. 1 move on the order of 10 m/s. Particles moving at 100s of m/s can be tracked with these fast cameras. Dust accumulation can be a problem for the coating of diagnostic windows and mirrors and dust will be a concern in future reactors, such as ITER for radioactive contamination and performance degradation.

Various image processing techniques can be used when images are cluttered or when the background light makes the particles difficult to discern. Background subtraction, thresholding, contrast enhancement, edge enhancement and moment calculations are used to clarify the particle locations. By knowing the locations of the cameras in NSTX coordinates, the pixel locations of the particles, and positions of various reference points within each camera’s field-of-view, lines can be computed connecting the camera lens with the particles (see Fig. 2). With 2 lines in three dimensions, the

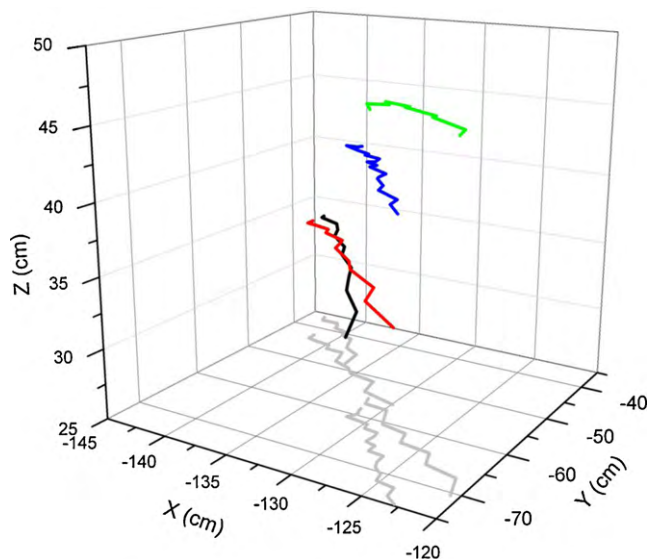


Fig. 3. Two cameras are used to compute 3D position (from Boeglin [12]).

intersection of the lines can be computed, or the mid-point of the closest distance between the two lines, if they do not intersect. If the distance between lines is not within 5 cm of each other, the point is discarded.

Fig. 3 shows three-dimensional trajectories of particles recorded in NSTX from these two cameras reconstructed with the Dust Track Reconstruction Code (DTRC) [12]. The jagged paths of the particles are suspected to be numerical artifacts, but may indicate something physical, such as interactions with filaments passing through the volume. More investigation is needed here. Data from DTRC can be used to validate theoretical transport codes such as DUSTT [13]. To validate the DTRC code, a grid was put on two walls in the corner of a room and two Phantom cameras were pointed at the corner from different angles. A ball was rolled down a ramp next to one wall, swung on a pendulum, etc. Positions of the ball in time were then known analytically. Plots of the computed positions in these tests agreed with the known locations of the balls.

5. Summary

Fast 2D cameras are excellent sources of information for operating a fusion experiment and for understanding important internal processes in plasmas. The data loads, which can easily be several times the size of all other shot-data combined, are a challenge for timely acquisition and retrieval, and for efficient storage. Likewise, new analysis methods are needed to digest these vast amounts of information and to understand the physics being revealed. Results presented here suggest that improvements to widely used data storage standards, such as compression methods optimized for plasma video data, would be cost effective. The obvious benefits of these systems may not justify the excessive access times and storage space for some users. Tracking small, quickly moving particles in a plasma is an image-processing challenge, and more work is needed to validate and extend existing codes.

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