IFDT – Intelligent In-Situ Feature Detection, Extraction, Tracking and Visualization for Turbulent Flow Simulations

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Abstract: This paper presents a new visualization and CFD data analysis system for flow feature data tracking and extraction. Known as Intelligent In-Situ Feature Detection, Tracking and Visualization for Turbulent Flow Simulations (IFDT), the system utilizes volume rendering with an Intelligent Adaptive Transfer Function that allows the user to train the visualization system to highlight flow features such as turbulent vortices. A feature extractor based upon a Prediction-Correction method then tracks and extracts the flow features and determines the statistics of features over time. The method executes In-Situ with a flow solver via a Python Interface Framework to avoid the overhead of saving data to file. This prototype system enables the user to readily explore, detect, track and analyze flow features predicted by large scale CFD simulations.

Keywords: Feature Detection, Computational Fluid Dynamics, Turbulence, Visualization, In-Situ, Feature Tracking.

1 Introduction

Large scale scientific and engineering physics based simulations have become more attainable with the advent of more affordable computing. Whereas ten years ago large scale computations were steady and on the order of 10's of millions of grid points, today's large scale computations are unsteady and on the order of 100's of millions and exceeding billions of grid points. Furthermore, large scale computations contain a wealth of information as these computations can now resolve the turbulent behavior of the fluid, more accurately simulate multiple species due to mixing and reactions and capture complicated shock interactions.

However, to harvest the information contained in these computations, engineers need tools that can automatically detect pertinent flow features and extract pertinent information. Contemporary open source and commercial CFD Post-Processing software have built-in functionalities to automatically detect such flow features. For instance, FieldView has the capability to compare different data sets using its Data Set comparison tool. In addition, it has the capability to automatically detect vortex cores and separation and reattachment lines using either vorticity or eigenvalue analyses [1]. However, these tools and other feature detection tools as highlighted by Thompson et.al. [2] were developed for steady state flow fields. These methods lack the ability to sample and explore extensive unsteady data sets. They furthermore rely upon visualization techniques that compare images and require excessive user intervention.

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With the larger unsteady datasets now becoming available there exists the need to improve upon these techniques to be able to, for example, understand the statistical properties of flow features such as vortices, eddies, recirculation bubbles, etc. New tools are needed that allow for more straightforward feature extraction to yield better physical understanding of turbulent and inherently unsteady flow phenomena which will help one to predict and understand key physics in all speed regimes. The understanding gained from such tools would then allow practitioners and designers to conceive new and unconventional breakthroughs in new aeromechanical device by controlling combustion processes, aerodynamic loads, aero-acoustic and aeroelastic interactions.

To address these needs, a new visualization technique called “Intelligent In-Situ Feature Detection, Tracking and Visualization, (IFDT) has been developed. This method utilizes a Python-based framework that enables a Python wrapped flow solver to share, without I/O penalties, the pertinent data structures with an intelligent feature detection-tracking tool and visualization software. The intelligent feature detection and tracking algorithm allows knowledgeable domain experts (i.e. combustion turbulence or structural aero-acoustics experts) to use an interactive graphical front end tool to identify and pick features rendered in a few initial time steps of the solution. Then the system automatically tracks those flow features in time and gathers pertinent statistics of that feature.

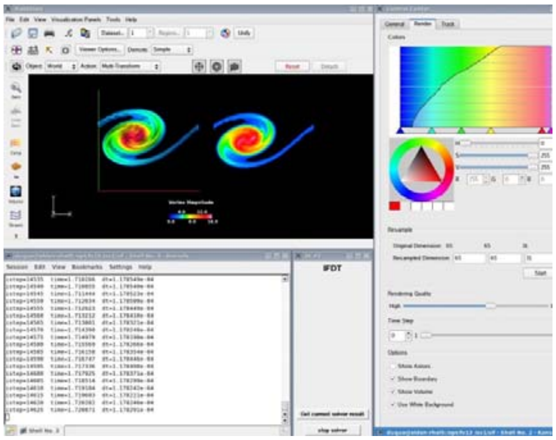

Figure 1 - The IFDT User Interface

2 Preliminary Results

Volume Rendering and the Predictor Corrector Feature Extractor and Tracking (PCFET) method by Muelder and Ma [3] was integrated into FieldView and then coupled via a Python framework [4] with the Large Eddy Simulation code LESlie3D [5]. Figure 1 illustrates FieldView version 13 with the PCFET environment and a LESlie3D case running in-situ with FieldView. The image shows both the Volume Rendered vortex on the left and polygonal rendered vortex on the right. The method works either in direct mode whereby all the tools execute on one desktop system or in a client-server mode whereby the solver and Predictor-Corrector method execute on a remote server while the Volume Rendering and User Interface run on the user’s local client.

The feature Training, “Picking” and “Extraction” capability by Akiba, Fout and Ma [6] has also been enabled. Figure 2 shows the IFDT Interface with the Feature Extraction and Picking panel shown. This panel allows the user to control the range of values that shall be tracked and extracted by interactively setting the minimum and maximum scalar value of voxels. The user then manually clicks on the feature shown in the volume rendering. The voxels of the feature of interest whose scalar value fall within the specified range are then colored by a single color; currently set to white. The volume

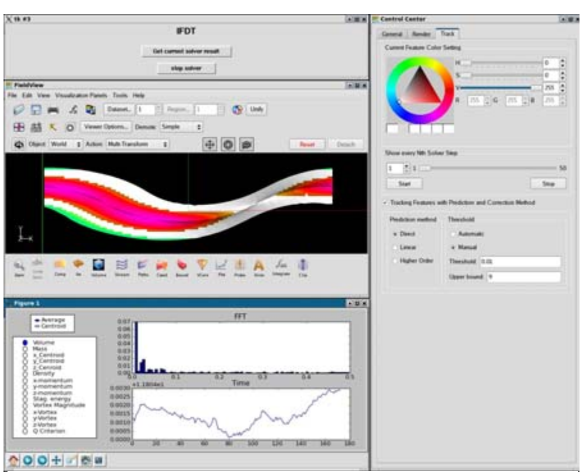

Figure 2 - IFDT User Interface with Feature Extraction and Picking

rendered image shown in the FieldView graphics window shows the resulting image of the vortex flow (colored voxels) and the picked voxels shown in white. The picked voxels are extracted and can be saved to disk as a feature extract for further study.

3 Conclusion and Future Work

This paper shall present a new visualization and CFD data analysis system for flow feature data tracking and extraction. Known as Intelligent In-Situ Feature Detection, Tracking and Visualization For Turbulent Flow Simulations, the system utilizes volume rendering with an Intelligent Adaptive Transfer Function that allows the user to train the visualization system to highlight flow features such as turbulent vortices. A feature extractor based upon a Prediction-Correction method then tracks and extracts the flow features and determines the statistics of features over time. The method executes In-Situ with a flow solver via a Python Interface Framework to avoid the overhead of saving data to file. This prototype system enables the user to readily explore, detect, track and analyze flow features predicted by large scale CFD simulations. The basic system has been built out and demonstrated on smaller scale problems. For the final paper, larger scale simulations will be performed with additional vortical features present. Various use cases shall be explored and studied.

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