Developing software for the study of transport consequences of electromagnetic drift wave turbulence in simplified Tokamak geometry

Submitted By

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Developing software for the study of transport consequences of electromagnetic drift wave turbulence in simplified Tokamak geometry

Major Project

Submitted in partial fulfillment of the requirements

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Master of Technology in Computer Science and Engineering (Networking Technologies)

Submitted By

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and

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

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Certificate

This is to certify that the major project entitled **"Developing software for the study of transport consequences of electromagnetic drift wave turbulence in simplified Tokamak geometry"** submitted by **Sweta Purohit (Roll No: 13MCEN32)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Networking Technologies(CSE) of Institute of Technology, Nirma University, Ahmedabad, is the record of work carried out by her under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Certificate

This is to certify that the Project entitled **Developing software for the study of transport consequences of electromagnetic drift wave turbulence in simplified Tokamak geometry** submitted by **Sweta Purohit(13MCEN32)**, towards the submission of the Project for requirements for the degree of Master of Technology in Networking Technologies(CSE) of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by her under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.

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Statement of Originality

I, **Sweta Purohit**, Roll. No. **13MCEN32**, give undertaking that the Major Project entitled "**Developing software for the study of transport consequences of electromagnetic drift wave turbulence in simplified Tokamak geometry**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science & Engineering** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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- Sweta Purohit
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Abstract

Nuclear fusion which provides tremendous energy is the solution for the depleting power resources. For nuclear fusion reaction it is necessary to overcome electromagnetic force of protons present in the nucleus which repel each other. This can be done by subjecting matter to immense heat through which it turns to plasma state. A Tokamak is a kind of a plasma confinement device which uses powerful magnetic fields to confine plasma into a very tight loop which is toroidal in shape. At very high temperature instabilities created causes hindrance in the plasma reaction. The CUTIE code helps to understand the instabilities affecting the nuclear fusion. This project aims at analysing the data obtained from CUITE code and providing useful inferences about the data. For this purpose an application developed will essentially extract useful data from dump files, analyse the data collected and visualise the data. Open source tools have been considered for the development of the application. Python along with third-party modules are used to develop the application.

Keywords

Plasma	It is one of the fundamental states of matter obtained on heating gas at high temperature or subjecting to very high magnetic field resulting in dissociation of molecular bonds.
CUTIE Code	Cutie code consists of equations to understand the tokamak instabilities.

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Chapter 1

Introduction

1.1 Institute For Plasma Research

Institute for Plasma Research(IPR) is an autonomous R & D organization under the authority of Department of Atomic Energy (DAE), Government of India. IPR is internationally recognized for its contributions to fundamental and applied research in plasma physics and associated technologies. IPR is playing major scientific and technical role in Indian partnership in the international fusion energy initiative ITER. IPR also develops industry specific plasma based technologies for societal and industrial applications. This institute is largely involved in theoretical and experimental studies in plasma science including basic plasma physics, magnetically confined hot plasmas and plasma technologies for industrial application.[1]

1.2 Background

In rapidly growing economy a fast growth is expected in the industrial and transportation infrastructure. Naturally, the energy requirements are set to ramp up at high values and the question of supply becomes a very important one. Energy drives everything, economy, social well-being, health and in essence, quality of everything. The conventional resources cannot fulfill our long-term needs, even when they are stretched to their maximum practicable limits.

In the present times of rapid human development across the globe, the proliferation of energy is a very basic need and a fundamental requirement of existence. Nuclear energy holds the promise of limitless energy potential as it possess a very high energy density.

The two basic tenants of nuclear energy namely Nuclear Fusion and Nuclear Fission are at the forefront of this immense 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 lethal waste products as a part of the fission process. Nuclear fusion on the other hand is clean and efficient with no harmful by products. Nuclear fusion, the merging of light atomic nuclei to form heavier ones, is an attractive option for large scale energy production. Fusion powers the sun and stars, and could on earth produce electricity from abundantly available fuels, without other hazardous emissions.

Fusion takes place when two or more nuclei come close enough for the strong nuclear force to exceed the electrostatic force and pull them together. To fuse, nuclei must overcome the repulsive Coulomb force. This is a force caused by the nuclei containing positively charged protons that repel via the electromagnetic force. To overcome this "Coulomb barrier", the atoms must have a high kinetic energy. This can be done by heating or acceleration. Once an atom is heated above its ionization energy, its electrons are stripped away, leaving just the bare nucleus: the ion. Most fusion experiments use a hot cloud of ions and electrons. This cloud is known as a plasma. Plasma is of a great technological and scientific importance in controlled thermonuclear fusion research.[2]

1.2.1 Tokamak

A tokamak is a kind of a device which confines plasma in the shape of a torus. Achieving a stable plasma equilibrium requires magnetic field lines that move around the torus in a helical shape. Such a helical field can be generated by adding a toroidal field (travelling around the torus in circles) and a poloidal field (travelling in circles orthogonal to the toroidal field). [3] Using a lateral and a orthogonal magnetic fields for confinement of the plasma, non-contact confinement of the plasma is achieved. This reaction is conducted in Tokamak at very high temperature. For the fusion reactions to occur, the fuel needs to be heated to 150 million degrees centigrade at several times atmospheric pressure. Under these conditions the atoms are fully ionised and form plasma. On reaction of these ions huge amount of energy is generated which is called fusion power.

At extremely high temperature nonlinear response of the plasma can be observed. Which cause plasma to colloid with the walls of the plasma reactor(tokamak).[4] This causes lot of instabilities being generated in the tokamak. This intern reduces the temperature so the nuclear fusion process is hampered. To yield more energy from the fusion than has been invested to heat the plasma, the plasma must be held up to certain temperature for some minimum length of time. This is the time period till which the plasma is maintained at a temperature above a specific temperature for nuclear reaction to take place.[5]. This time period is called confinement time. Confinement time in nuclear fusion devices is defined as the time the plasma is maintained at a temperature above the critical ignition temperature.[6]

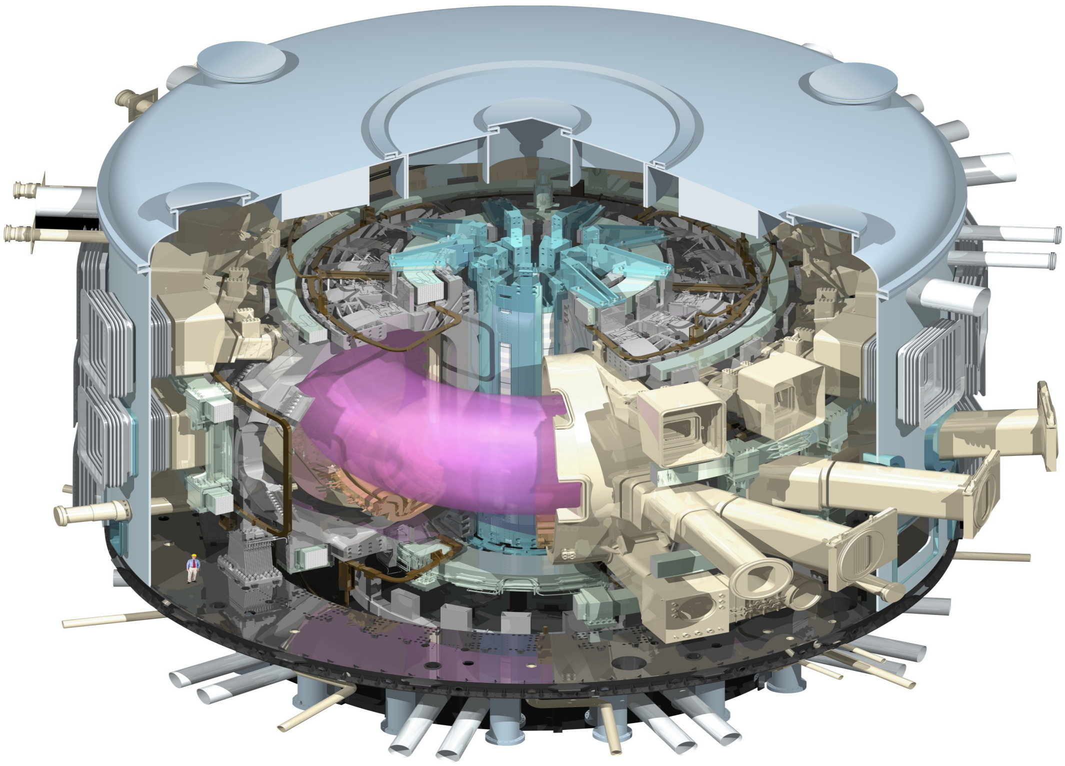

Figure 1.1: Tokamak

In a working reactor, plasma is required to be kept at high temperature. Hence it is important to minimise energy loss from the plasma reactor. Instabilities causing energy loss in the tokamak are gradients of density, pressure, current, and flow. Tokamaks also exhibit phenomena such as internal transport barriers, or regions of significantly reduced local radial transport and turbulence. Turbulence in the plasma causes disruption by transporting mass and energy away from this core, reducing the efficiency of the reaction.[7]

1.3 The CUTIE Code

Study of plasmas being a very arduous and costly affair, it is quite common for scientists to model a tokamak reactor and obtain inferences from these simulations. An approach to better understand plasma turbulence and anomalous transport involves global simulations for a two fluid plasma and Maxwells equations. Global simulations take into account length scales all the way upto device scale, and a two fluid theory accounts for the different physics of the ions and electrons by treating them as two separate interacting fluids.

CUTIE(CUlham Transporter of Ions and Electrons) is plasma fluid initial value code which provides such simulations. CUTIE is a quasi-neutral two-fluid computer model for turbulence in a toroidal plasma. The CUTIE model reproduces many observed features of the experiment qualitatively and suggests that global electromagnetic simulations may play an essential role in understanding tokamak turbulence and transport. [8]

Cutie code consists of set of equations amongst which each equation studies factors driving various instabilities arising in the tokamak. It tries to apply equations and processes to study instability in turn increasing the confinement time. Experiments conducted in the tokamak are affected by various instabilities. These instabilities influence the experimental results. In order to find out how and which instability has affected the result of the experiment the cutie code has been used. [9]

The cutie code has its own assumptions and various parameters are tested and results are obtained. The experimental parameters are set in the equations as an input in cutie code. The outcomes of the CUTIE code are tried to be adjusted so as to match the experimental outcomes.

1.4 Objective Of Study

Cutie code visualisation plays very vital role in understanding the results of the cutie code. The tokamak behaviour can be studied accurately by studying effects of different parameters like magnetic field, electric field,viscosity,resistivity etc.

The cutie code is run on set of data and generates binary dump file. The main aim of the system under analysis is to extract useful data from the dump files and to visualise it. The visualisation offered uses various plotting styles using various dimensions. The system aims to aid the user to change minute details and various features interactively and provide overall analysis of the data.

The system under analysis is created with a perspective for the user to get full details of the tokamak experiments using just the parameters fed to the tokamak without physically performing experiment in the tokamak. This document serves as a guide for the developments of such a system.

1.5 Scope

The document only covers the requirement specification for the visualisation system and a basic blue print of how to use the given experimental data sets. The work include conversion of the dump files to ASCII files and extraction of the necessary data and application of visualization techniques and related features. It does not specify the nature of experiments, conditions, outcome or inferences gained from these experimental data. It expedites inputs, user requirements and external interfaces and dependencies.

1.6 Problem Statement

A lot of collaborative effort all over the world is under-way to understand,build, study and advance Plasma research. CUTIE code consisting of set of equations which helps in identifying the instability in the tokamak. The experimental results of the tokamak and the CUTIE code results are mapped to identify nature and type of the instability. In order to successfully setup the nuclear fusion we need to remove the instability. For this reason various parametric values need to be closely observed inside the tokamak at various conditions.

CUTIE code acts as a tool for theoretical computation of the tokamak experiments. CUTIE code involves huge computation with Fourier series and complex calculation of the equation. This type of computation manually is cumbersome and time intensive. In order to facilitate easy computation an automatise computation of this CUTIE code an application has been developed. This application gives results in form of binary dump files. These binary dump files contain huge set of numerical data pertaining to each parameter. For this reason the analysis and understanding of the CUTIE code results becomes a herculean task.

Data visualization is the study of the visual representation of data, meaning Information has been abstracted in some meaningful schematic form, including attributes or variables for the units of information. The main goal of data visualization is to communicate information clearly and effectively through graphical means. Data visualization is a means of extracting data pertaining to a study and then using tools and techniques well defined to abstract meaningful inferences from the data such collected. To convey ideas effectively, both aesthetic form and functionality need to go hand in hand, providing insights into a rather sparse and complex data set by communicating its key-aspects in a more intuitive way. Effective visualization helps users in analysing and reasoning about the data and evidence. It makes complex data more easily accessible, understandable and usable. Some major aspects of visualization are discussed in order to set the tone of this discussion. Data visualization refers to the techniques used to communicate data or in formation by encoding it as visual objects contained in graphics. The goal being to communicate information clearly and efficiently. It forms on of the major steps in data analysis/science, i.e extracting meaning out of potentially unrelated data.

Data visualization is closely related to information graphics, information visualization, scientific visualization, exploratory data analysis and statistical graphics. It is believed by many to be a branch of descriptive statistics. Data visualization is both an art and science. The rate at which data is generated has increased, driven by an increasingly information-based economy . Data created by Internet activity and a expanding numbers of sensors in the environment, such as satellites and traffic cameras, are referred to as BIG DATA. Processing, analysing and communicating this data present a variety of ethical and analytical challenges for data visualization. The field of data science has emerged due to such an increase in data.

In order for the visualization to be effective, i.e for it to convey complex ideas with clarity, precision and efficiency some common traits are to be followed. Users of visualizations are executing particular analytical tasks such as making comparisons, determining causalities. Hence the visualization should be such that it promotes such tasks. Following are some of the characteristics that any visualization must try to achieve :

- Show the data.
- Induce the viewer to think about the substance rather than about methodology,

graphic design or technology used for the graphics.

- Avoid distorting what the data has to say.
- Present many numbers in a small space.
- Make large data sets coherent.
- Encourage the eye to compare different pieces of data.
- Reveal the data at several levels of detail, from a broad overview to the fine structure.
- Serve a reasonably clear purpose:description, exploration, tabulation or decoration.
- Closely integrate with statistical and verbal descriptions of a data set.

The fact that visualization are better able to communicate data more effectively is that humans can distinguish differences in line length, shape orientation and color readily without significant processing effort. This is termed as pre-attentive attributes. Effective graphics must take advantage of this pre-attentive attribute in order to present the data which is more visually descriptive but also retains the information that it aims to convey.

The system aims at providing ease to the user in understanding complex results without having to deal with enormous numerical sets of data. The motive of this system is to present the results in form of graphical visualization. The system aims the user to aid interactively observe effects of changing parameters visualization. The application to be developed helps to analyse the instabilities visually by varying time scale and parameters. It extracts data from the dump files and performs computation on it.

The acquired data is required to be accounted for and also important statistical and analytical inferences are to be extracted from this data. For deeper insight data needs to be visualised in from of important 2D and 3D plots of various types. Interactive graphical components of the plot help in in depth analysis of the CUTIE results.

Tokamak experiment involves very complex study of number of parameters. In order to study analyse and visualize them a computerised system is needed. Using a computer for processing large quantities of data is quite a natural choice. Creating an application for the visualisation and statistical analysis of the experimental data is thus at the heart of the project.

1.6.1 Thesis Organization

The rest of the thesis is organized as follows:

Chapter 2, Literature Survey, describes the review of the past contribution in this field.

Chapter 3, Hardware Software Specification, describes the requirements for the system along with the basics about technology used in the system development. Chapter 4, System Design , covers Block diagram and flowchart.

Chapter 5, System Implementation

Chapter 6, Summary and Conclusion

Chapter 2

Literature Survey

2.1 Reviews of related works

Related software Knightscope

Knightscope is an application developed by Professor Peter Knight based on Professor Anantanarayanan Thyagaraja. This application is developed using IDL(Interactive Data Language). Knightscope performs CUTIE simulations and provides an insight to the changing experimental parameters within the tokamak in form of various plots. The plots obtained give overall analysis of the tokamak in multiple dimensions. Knightscope provides functionality of observing the graphical representation of changing parameters of the tokamak.

Interactive data language (IDL) is a programming language used to build applications performing data analysis. IDL is vectorized, numerical, and interactive data programming language and is commonly used for interactive processing of large amounts of data (including image processing). Oriented toward use by scientists and engineers toward visualization of multidimensional data-sets. IDL is mostly utilized by astronomers and medical imaging experts. It offers all the power, adaptability, and programmability of high level languages. [10]

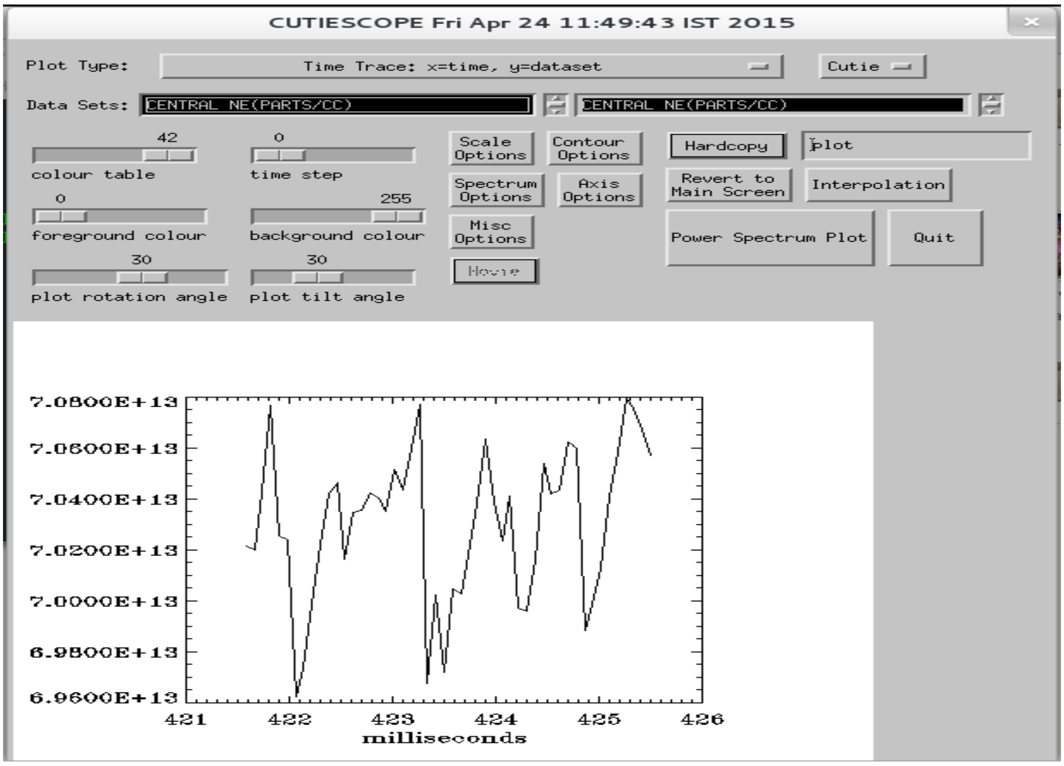

Figure 2.1: Knightscope in IDL

IDL as a commercial language is complete in the sense that most of the tools required for application development are all mostly inbuilt via proprietary libraries, but this in essence is its undoing. IDl which is a base for construction for knightscope is licensed. So the use of knightscope incurs lot of financial burden on the user. This limits the scope usage of the application. For a project of the scale and scope as described above, its lack of open structure prevents data, code and results from being openly distributed and shared.

Knightscope application in IDL has been coded in a sequential format. As the scientists start using the application they identify small minute modifications needed to be incorporated in the application for the ease of use. The knightscope coding structure being sequential in nature the modification when applied becomes difficult. The code modification when applied in one part of code may affect other parts of code as well.

IDL is suitable for moderate size datasets. CUTIE code experiments deal with large arrays whereas IDL is slower while dealing with large arrays and the array functionality is also less powerful in such cases. The handling of datasets using array is complicated which can cause a serious problem in visualization.

There many good frameworks available for better visualisation features and facilities but those can not be used with IDL. This is because it has single widget system and it is useless if working with other framework.

Application under study is mainly based on plotting functionality. IDL has poor support for plotting features. Plotting issues include portability issues, flexibility issues,not intrinsically interactive plot windows. [11]

Over the years knightscope has been used and the users have identified several difficulties in terms of features missing in the application. The graphical plots give more idea when observed closely. For this reason the scaling of minimum and maximum needs to be changed to user specified values. This would help user to minutely changes in the graphical lines. A graphical plot created using log/Linear and Log/Log of the data would also be helpful for detailed analysis of the results.

Till date the use of knightscope was inevitable to study the cutie code results. Several shortcomings have been identified while its use as stated above. The motive of overcoming these shortcomings draws us to dire need of creation of new visualisation system for cutie code results.

Chapter 3

SOFTWARE REQUIREMENT SPECIFICATION

3.1 Functional Overview

The successful implementation hinges on the understanding of the user requirements and the services that the software is expected to provide to the user. Each requirement should be specifically organised in a document called Software Requirement Specification (SRS).

SRS provides complete description of the system to be developed. It contains the software requirements details like front-end technology, back-end technology, operating system and hardware architecture of the project.

It also describes the functional and non-functional requirements in the project. Functional requirements correspond to the software provided to the user. Non-functional requirements correspond to various factors such as environment, end user characteristics etc.

The SRS is produced at the culmination of the analysis task. The function and performance allocated to the software as a part of system engineering and refined by establishing a complete information description, a representation of system behaviour, indication of performance requirements and design constraints, appropriate validation criteria and other information related to requirements. The SRS is a technical specification of the requirement of the experimental Data visualisation application system. The specification describes what the proposed system should do without describing how to do it. It describes the complete external behaviour of the proposed system.

3.2 Product requirements

For system under consideration we need a coding language which can fulfill specific demands of the system. The primary requirement for the system is using open-source technology for the system. A language which can handle huge numerical data in an organised manner. The numerical data handling needs to be very accurate as any error in handling may affect drastically to graphical plot. The basic requirement of our system is visualization so the technology used should offer excellent visualization or support for such packages. The technology used should aid support for various packages and should be flexible.

For the type of system under consideration python is suitable language. Python is a high-level programming language designed to be easy to read and simple to implement. It is open source, which means it is free to use, even for commercial applications. Python offers more general array capabilities and is faster for large arrays. Plotting framework is more extensible and general. It has better font support and portability. Standard plotting functionality is independent of framework used. Plots are embeddable within other GUI's and offers more powerful image handling.

3.3 Hardware and Software Requirements

3.3.1 Hardware Requirements

CPU	Intel Pentium 4 or greater
AMD	Athlon X2 or greater
RAM	1GB or greater
Hard disk	8GB or greater
For best performance Any GUI based terminal having at least 800 * 600 256-color displays.	

Table 3.1: Hardware requirements

3.3.2 Software Requirements

OS	Windows 7 or greater or suitable Linux distro with kernel version 2.6 or greater
Python	verison 2.7.6
Numpy	version 1.8.2
PyQt	version 4
Qt framework	version 4
matplotlib	version1.4.3
scipy	version 0.15.0

Table 3.2: Software requirements

3.3.3 Numpy

NumPy is the fundamental package for scientific computing with Python. It contains among other things:

- A powerful N-dimensional array object
- Sophisticated (broadcasting) functions
- Tools for integrating C/C++ and Fortran code
- Useful linear algebra, Fourier transform, and random number capabilities

Besides its obvious scientific uses, NumPy can also be used as an efficient multi-dimensional container of generic data. Arbitrary data-types can be defined. This allows NumPy to seamlessly and speedily integrate with a wide variety of databases. Numpy has been extensively used for multidimensional array handling and mathematical functions in the system.

3.3.4 Scipy

SciPy is an open source Python library used by scientists, analysts, and engineers doing scientific computing and technical computing. SciPy contains modules for optimization, linear algebra, integration, interpolation, special functions, FFT, signal and image processing, ODE solvers and other tasks common in science and engineering. SciPy builds on the NumPy array object and is part of the NumPy stack which includes tools like Matplotlib, pandas and SymPy.

3.3.5 Qt

Qt is used mainly for developing application software with graphical user interfaces (GUIs). Qt is a cross-platform application framework that is widely used for developing application software that can be run on various software and hardware platforms with little or no change in the underlying codebase, while having the power and speed of native applications. GUI programs created with Qt can have a native-looking interface, in which cases Qt is classified as a widget toolkit.

3.3.6 PyQt

PyQt is a Python binding of the cross-platform GUI toolkit Qt. It is one of Python's options for GUI programming. Like Qt, PyQt is free software. PyQt is implemented as a Python plug-in. PyQt supports Microsoft Windows as well as various flavours of Unix, including Linux and OS X. It has extensive set of GUI widgets. The PYQT framework used in the system for python binding with QT framework.

3.3.7 Matplotlib

Matplotlib is a python plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms. Matplotlib can be used in python scripts, the python and ipython shell.

It provides an object-oriented API for embedding plots into applications using general-purpose GUI toolkits like Qt.

Chapter 4

SYSTEM DESIGN

Systems design is the process of defining the architecture, components, modules, interfaces, and data for a system to satisfy specified requirements. The purpose of the design phase is to plan a solution of the problem specified by the requirements document. The design of a system is perhaps the most critical factor affecting the quality of the software, and has major impact on the later phases, particularly testing and maintenance. The output of this phase is the design document. Systems design is the process of defining and developing systems to satisfy specified requirements of the user.

The system is organised in modularised format into aid easy flow and understanding. The is designed keeping in mind the future requirements of the changing demands. Individual modules contain the separate structure for each type of graphical plot and the added features and functionality which can interactively applied on the graphical plot.

4.1 System Block diagram

The system Block diagram gives overall idea of the system of the CUTIE code. This whole system in the block diagram can be substituted for the functioning of the tokamak. As shown the required values for the specific parameters are fed to the system as an input. Using these values the CUTIE code computation are applied containing complex calculation. These CUTIE code equations are basically fourier series and partial differential equations calculation using huge dataset which is very difficult for manual computation. CUTIE code is a FORTRAN code which simulates a simple geometry (linear) tokamak with various parameter switches to control the level of complexity the simulation incorporates. The output of the CUTIE code is a sequential, unformatted dump file which is the output pertaining to the simulation performed. The output results are in form of binary dump files. These are again fed to our application. The application convert the binary files to ASCII and applies processing on it. The data for analysis containing huge set of numerical datasets are graphically depicted. This produces visual data analysis for the results which can be interactively adjusted to observe the results minutely.

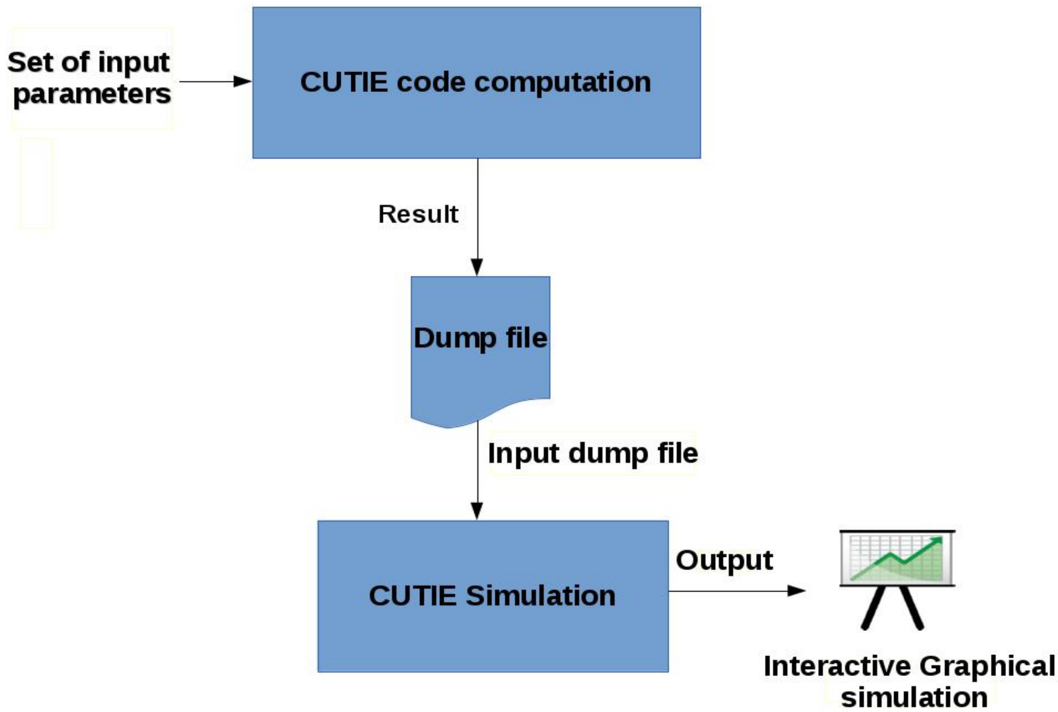

Figure 4.1: Block Diagram

Designing flowchart of the proposed system

A flowchart is a type of diagram that represents an algorithm, work flow or process, showing the steps as boxes of various kinds, and their order by connecting them with arrows. This diagrammatic representation illustrates a solution model to a given problem.

The software design has been modularised. As shown in the flowchart initially the dump files are fed to the system which are sent to a module called dump extractor for ASCII conversion of the binary dump files. The dump extractor returns the ASCII format of the data. This ASCII file contains immense numerical data which needs to be organised and visualized.Proper structuring and computation of the data is applied upon this numerical data and necessary data for visualization for scientific analysis is extracted. The GUI window gets created for user interaction.

The user can then choose different plot types according to parameters needed for observation. Upon choosing the plot type the event handler interactively runs the respective module for the plot and the associated parameters get visualized according to user's selection. Apart from the plot types different other parameters can also be changed for plot under observation. The datasets,minimum and maximum scaling of the plot,hardcopy option to save the generated results and plots,animation in plots in form of movie,changing contour levels can be interactively changed and is handled by the event handler which calls respective module and gets implemented for the user. These changes get applied using a event handler until the user clicks on close button.

Major procedures have been identified and depicted. The application for scientific use it is required to be very robust and error-free. A event handler exists to determine user intentions with the GUI and appropriately calls the required module for handling procedure for actions.

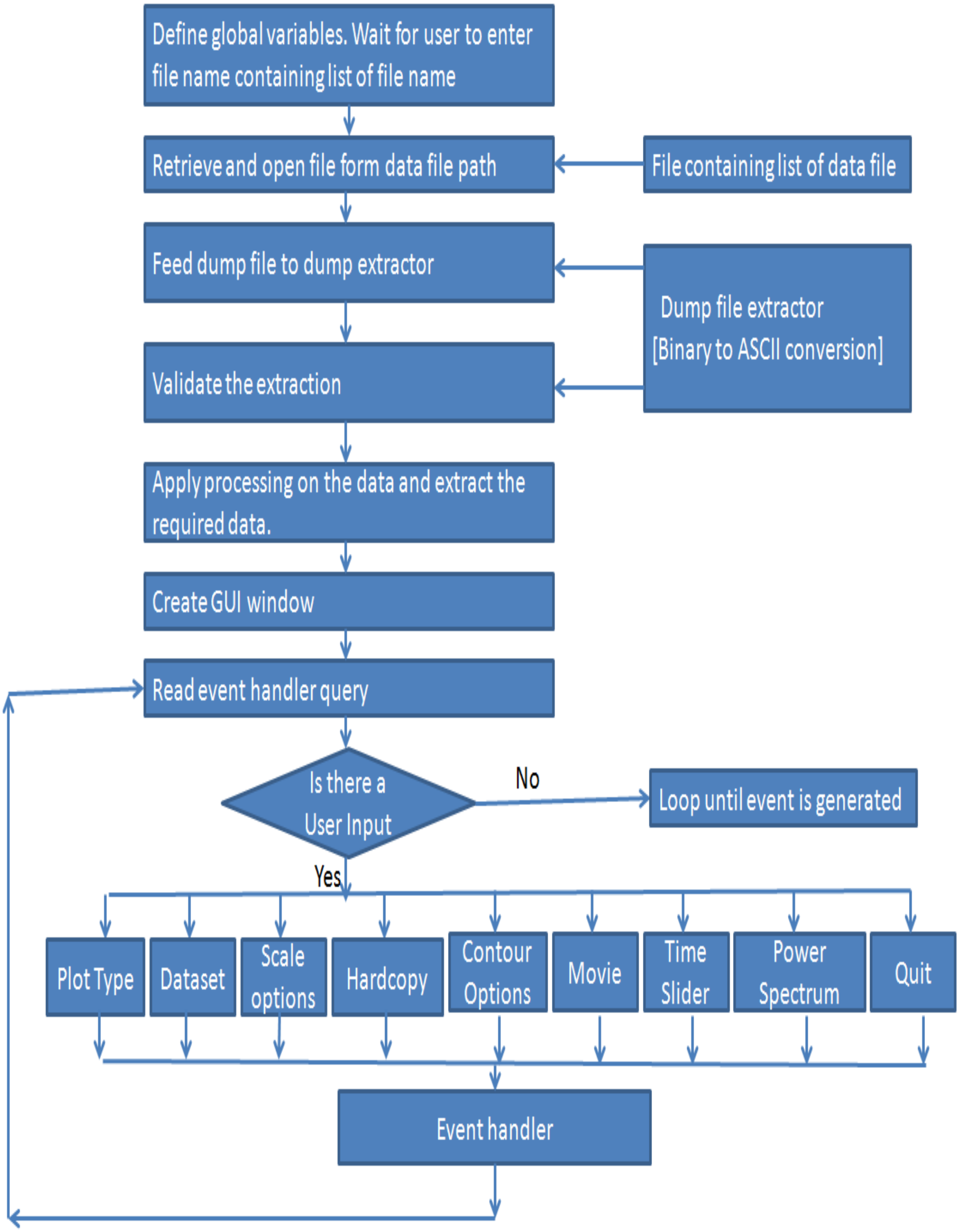

Figure 4.2: Flowchart

Chapter 5

SYSTEM IMPLEMENTATION

Implementation is the realization of an application, or execution of a plan, idea, model, design, specification, standard, algorithm, or policy. Systems implementation is the construction of the new system and the delivery of that system into production (that is, the day-to-day business or organization operation). The construction phase does two things: builds and tests a functional system that fulfills business or organizational design requirements, and implements the interface between the new system and the existing production system.

5.1 Product Functions

The system under the study contains important functionality for the scientist to get an insight into the tokamak. The functionalities provided in the system have been implemented keeping in mind the requirements and ease of the scientists. The basic funcltionality provided by the system is as listed below.

To extract data from given dump files

Initially user gets prompted for name of file containing list of dump file names. The names of the dump files are directly extracted from a file which contains names of list of dump files. The data of various experimental results to be analysed are fed in form of the dump file for processing and visualization.

Provide means to choose plot types for data visualisation

Tokamak analysis involves data of number of parameters. Different set of parameters need to be analysed by different types of graphical plots. Various Plotting options are provided. The types of plots provided are described below.

- **Time Trace Plot**

  A two dimensional plot is being plotted where dataset containing tokamak parameters are being plotted against time frame. It is used to observe effect of a parameter at changing instances of time while experiment within the tokamak.

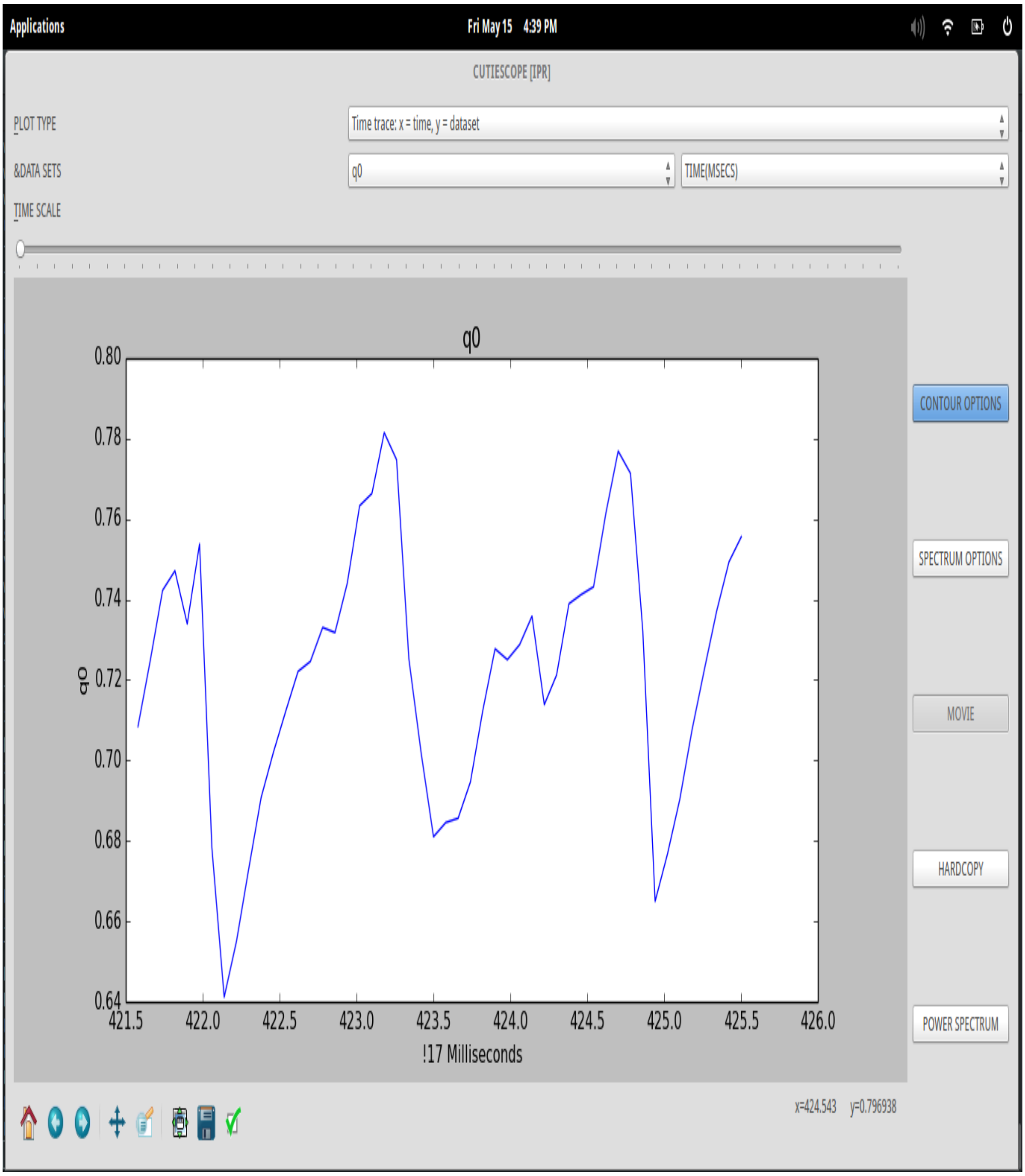

Figure 5.1: Time Trace

- **The Profile Plot**

  It is a two dimensional plot where the X axis determines r/a that is aspect ratio of the tokamak and Y axis denoted the dataset. This plot is used to determine where each dataset is radially with respect to the tokamak at single instant of the time.

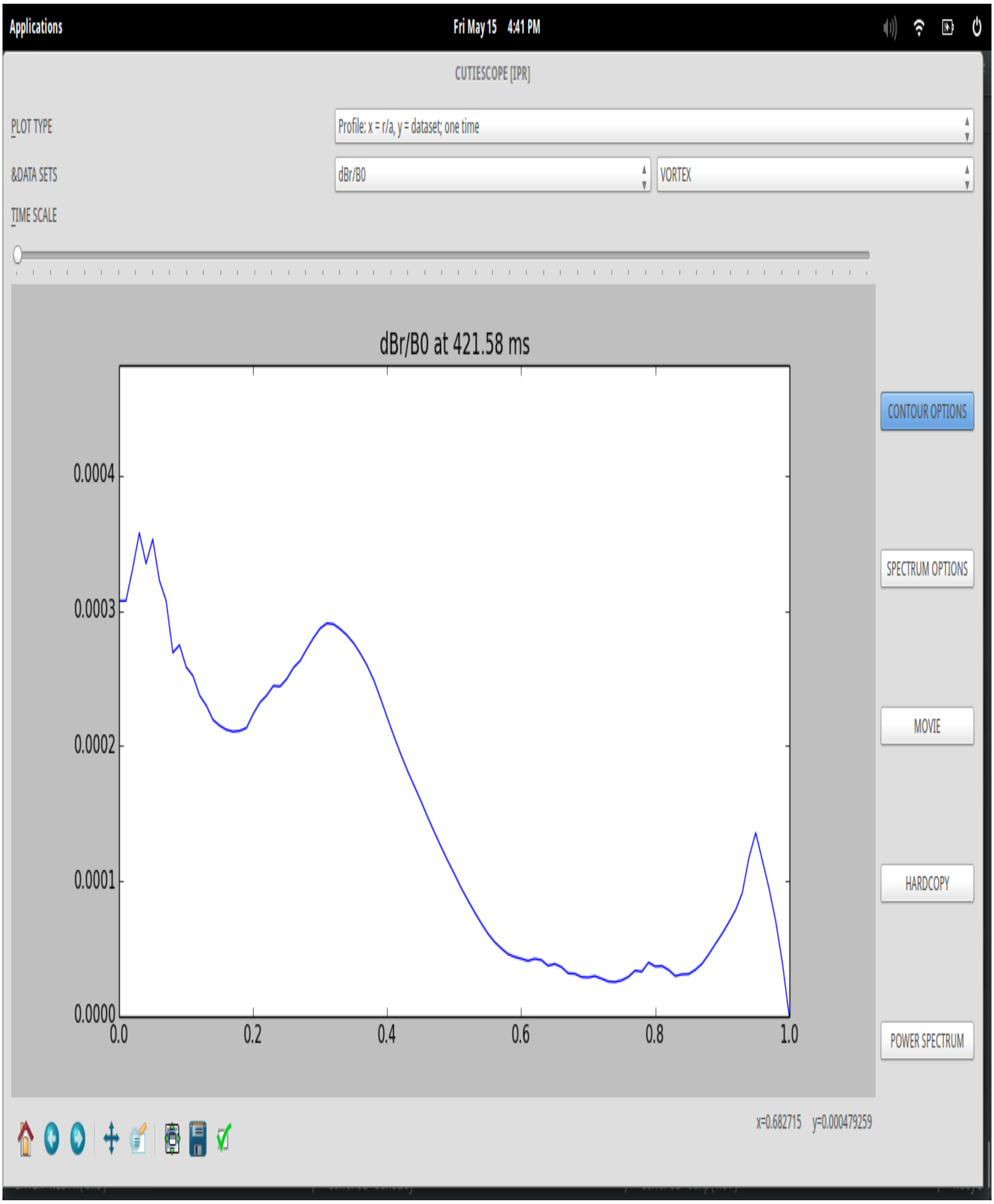

Figure 5.2: Profile Plot

- **Surface Plot**

  It is three dimensional plot with time , r/a and dataset as the three axis. A surface chart is useful when you want to find optimum combinations between two sets of data.

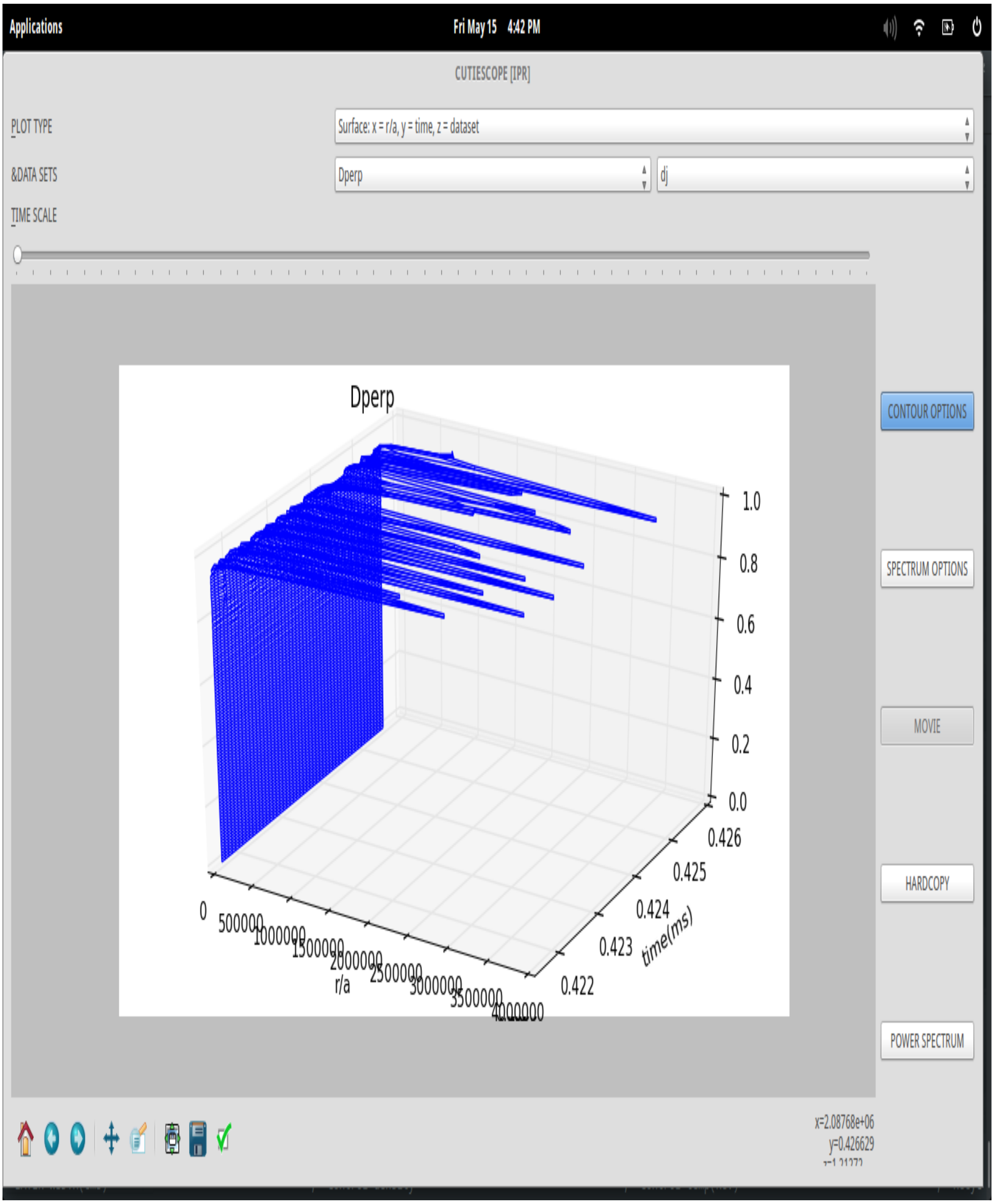

Figure 5.3: Surface Plot

- **Contour Plot**

  A contour plot is a graphic representation of the relationships among three numeric variables in two dimensions. Two variables are for X and Y axes, and a third variable Z is for contour levels. Here contour denotes poloidal plane with datasets color coded at single instant of time.

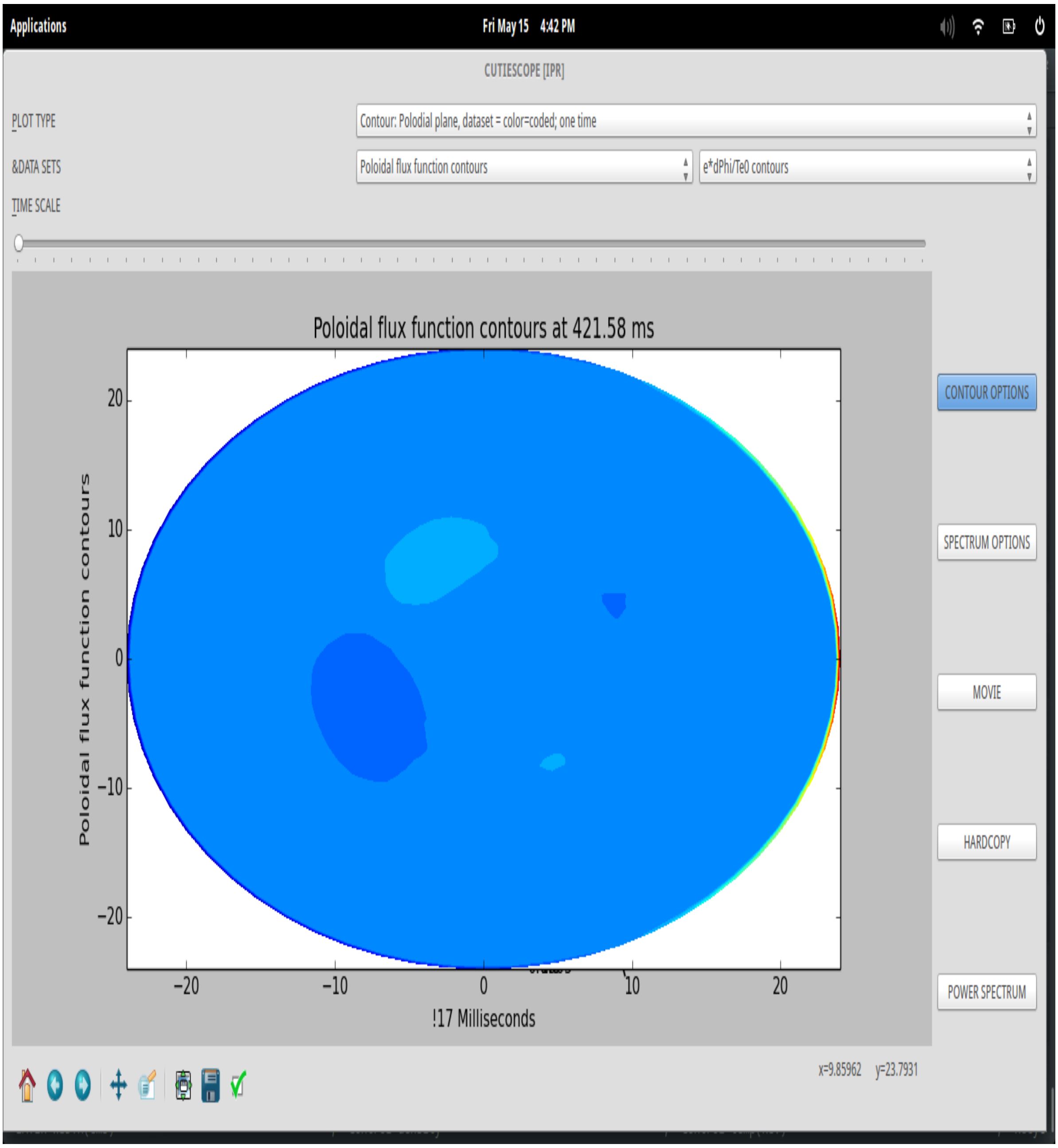

Figure 5.4: Contour Plot

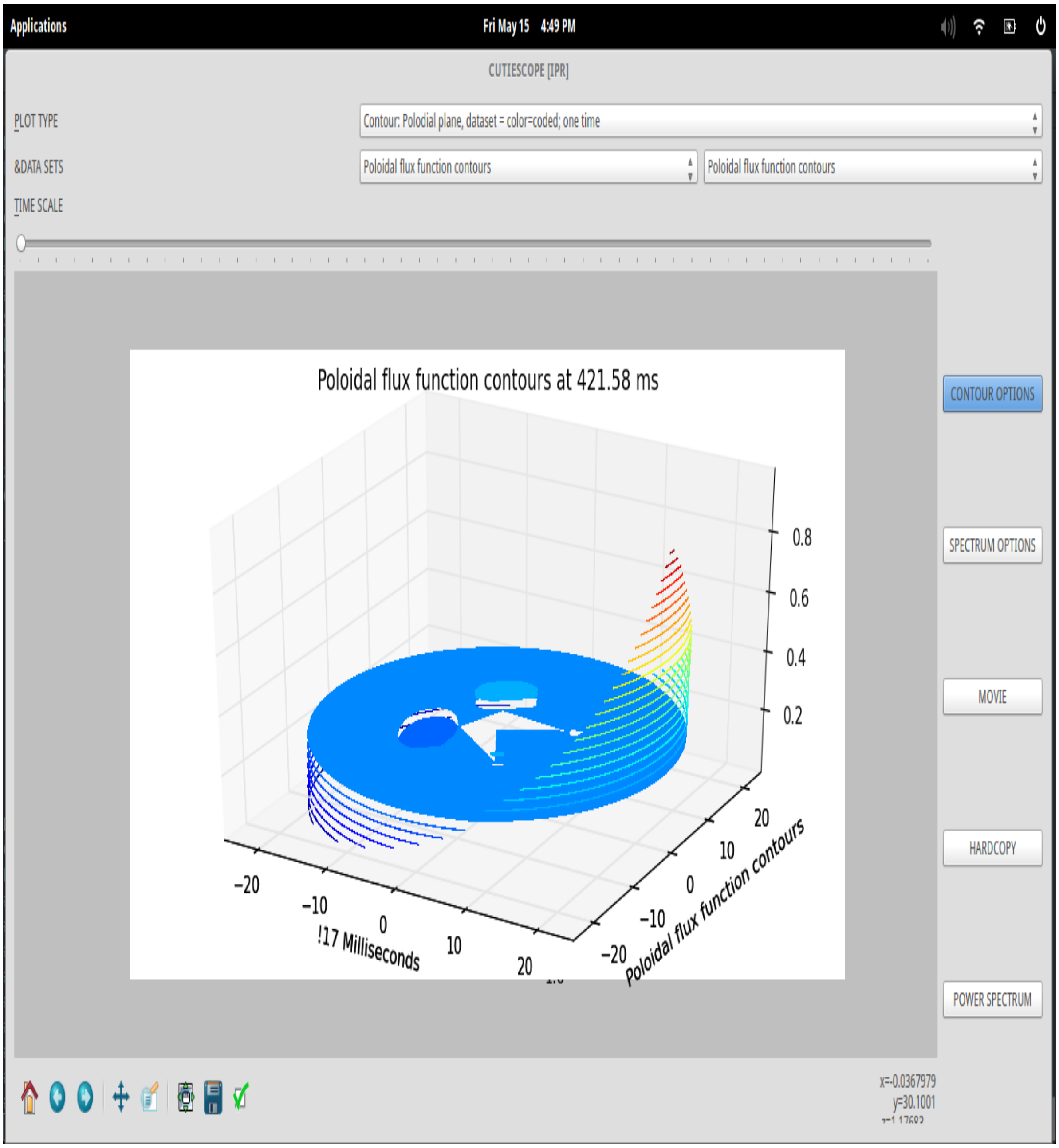

Figure 5.5: Contour Plot in 3D

- **Spectrum Plot**

  It is a graphical technique for examining cyclic structure in frequency domain. It is used to to calculate displacements and stresses in the model. It is used to determine the response of structures to random or time-dependent loading conditions.

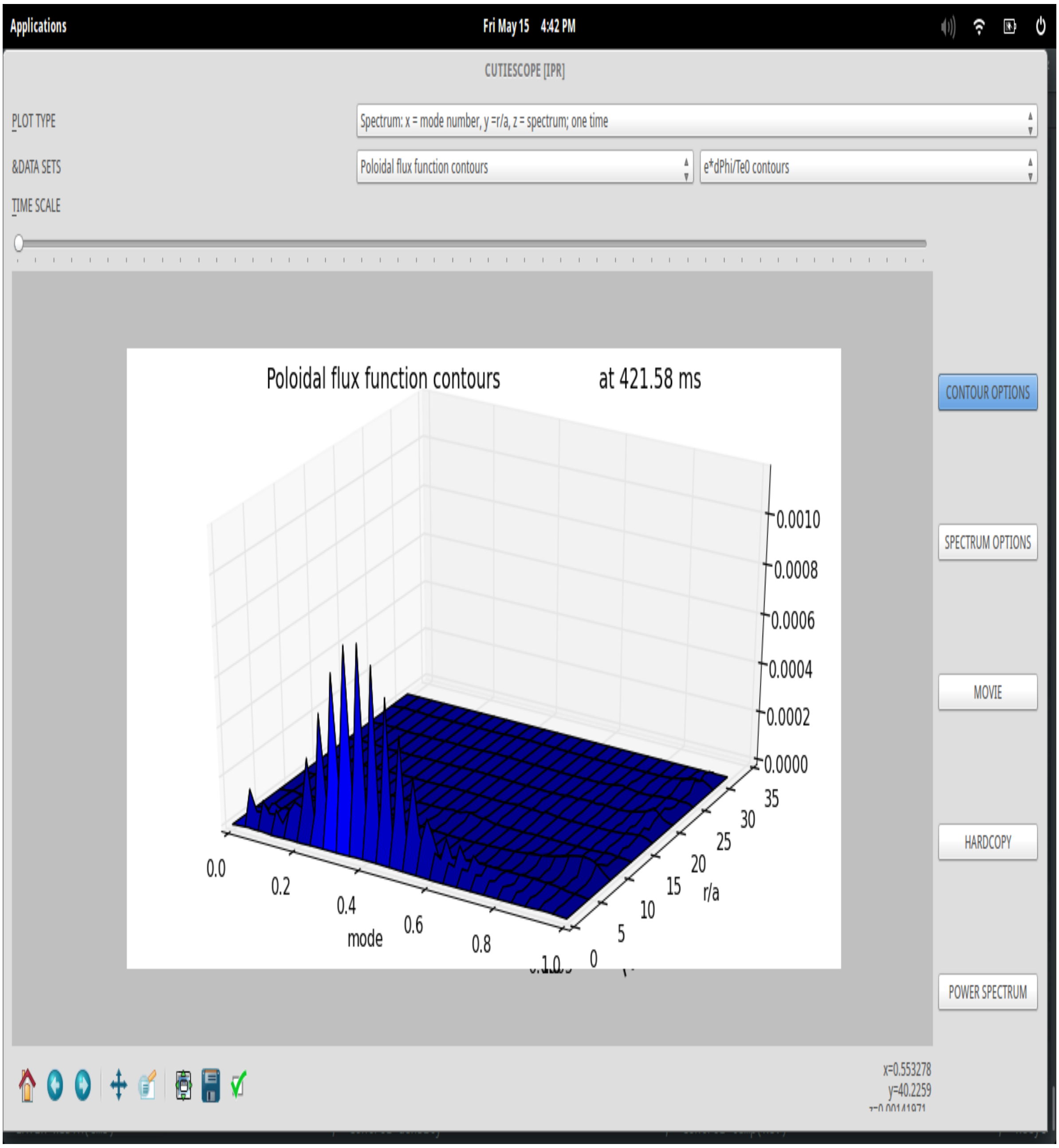

Figure 5.6: Spectrum Plot

- **Power Spectrum Plot**

  It shows the distribution of the energy of a waveform among its different frequency components. Power spectrum for different datasets is plotted.

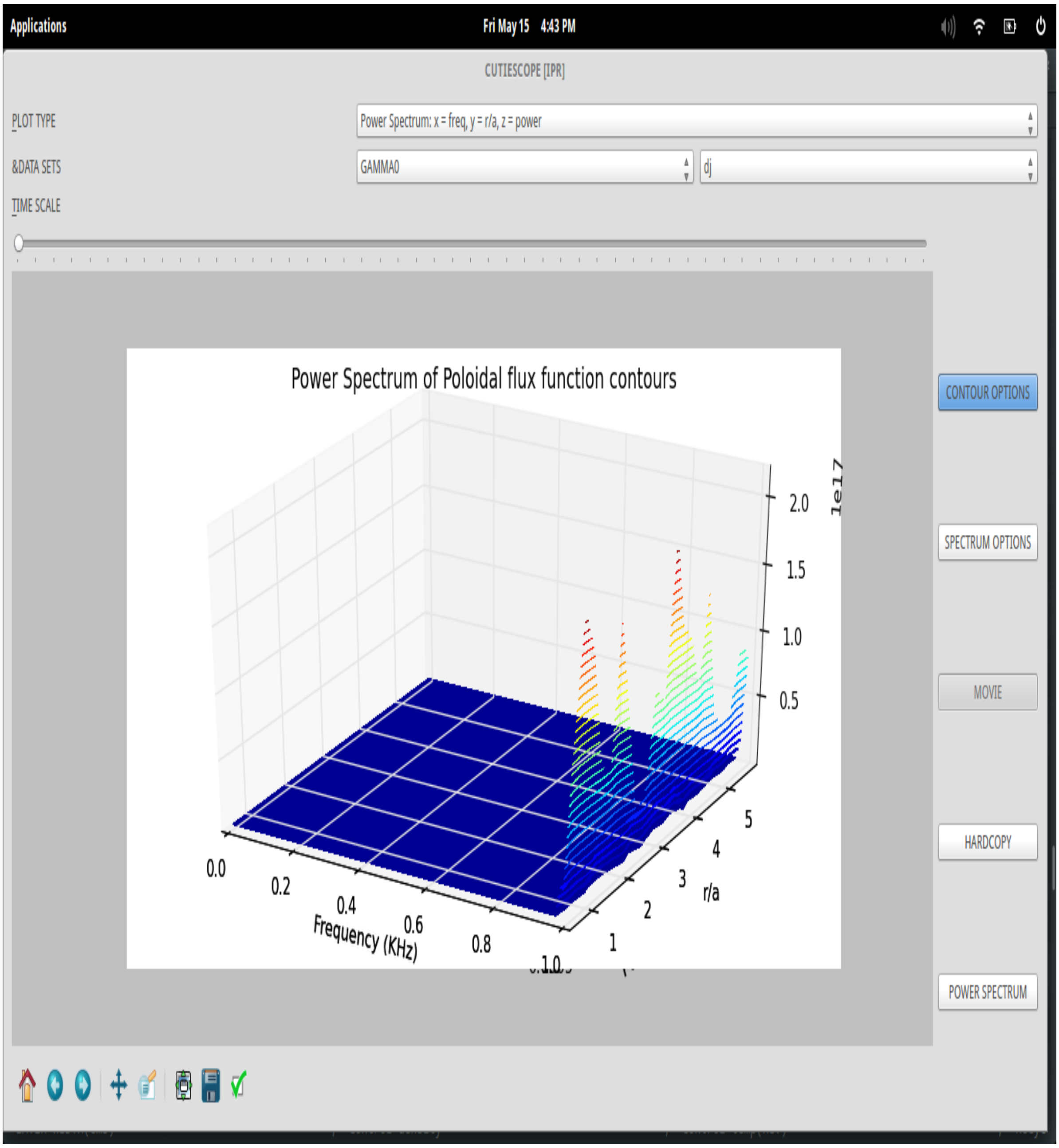

Figure 5.7: Spectrum Plot

To generate plot with varying datasets

For each type of plotting analysis different experimental parameters can be observed. The values of these parameters are evaluated with changing time scale or aspect ratio. These parameters are plotted as the axes parameters.

Observe changing parameters with changing time step

When the dataset is plotted for different axes parameters keeping time instant fixed this feature is useful. The time step option provides option to observe changing dataset value in the plot for different time instant.

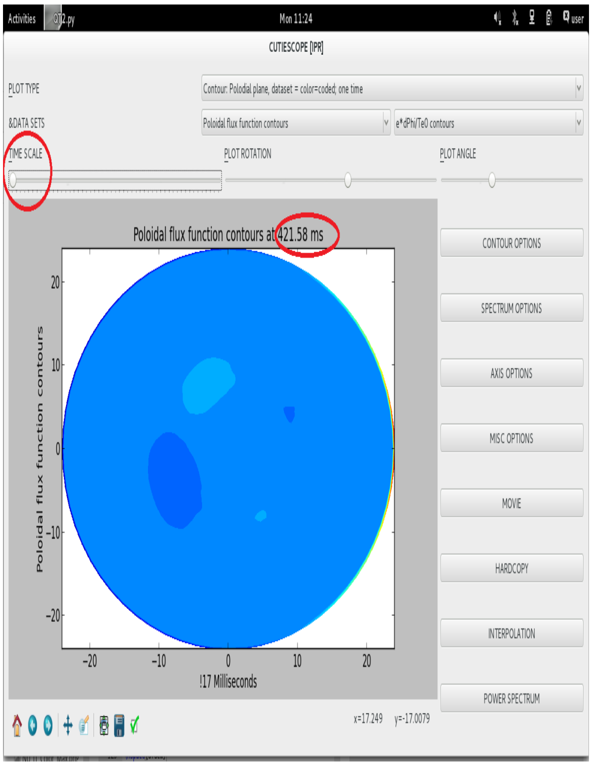

Figure 5.8: Plot with changing time step

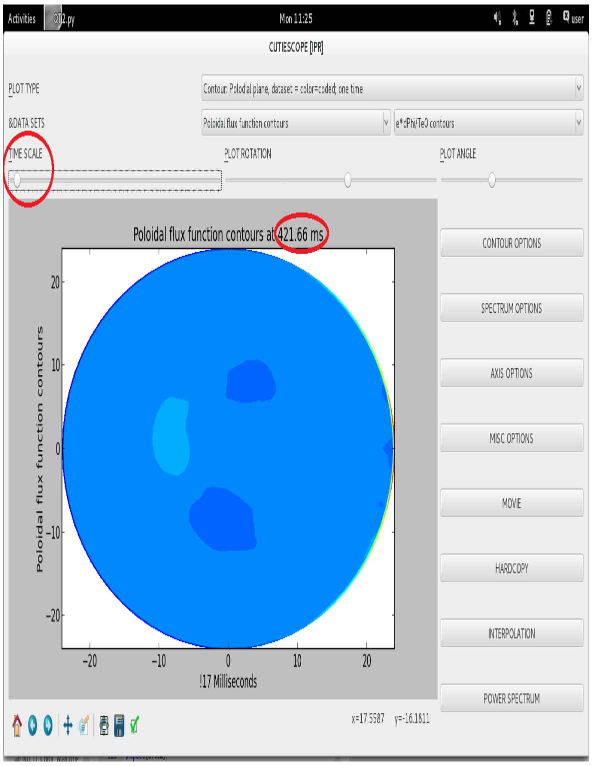

Figure 5.9: Plot with changing time step

Provide means to rotate plot by any angle

In an 3D plot there is a need to observe the plot with different sides to observe plot accurately. The plot can be rotated by any angle to closely observe even minute fluctuations on the datasets.

Provide scaling options

The scales can be adjusted to observe a minute variation of plot. The plot can be scaled according to user specified minimum value or user specified maximum value or user specified minimum and maximum value. Through interpolation new data points can be found within given discrete data points.

Provide a means to save analysed data as hard copy

System offers the plotted data to be saved in order for further reference or to get print out and save it as hard copy. This hard copy option offers two type of method to save plotted results in the computer. The plots can be saved as image in postscript files,portable network graphics,Joint photographic experts group etc. The plot specifics can also be saved as a text file. The text files contain the coordinates of the plot. The coordinates can then be even used to visualize in GNU plot to provide an alternative visualization. This aids the user to save the plotted result and easily refer for future analysis and study.

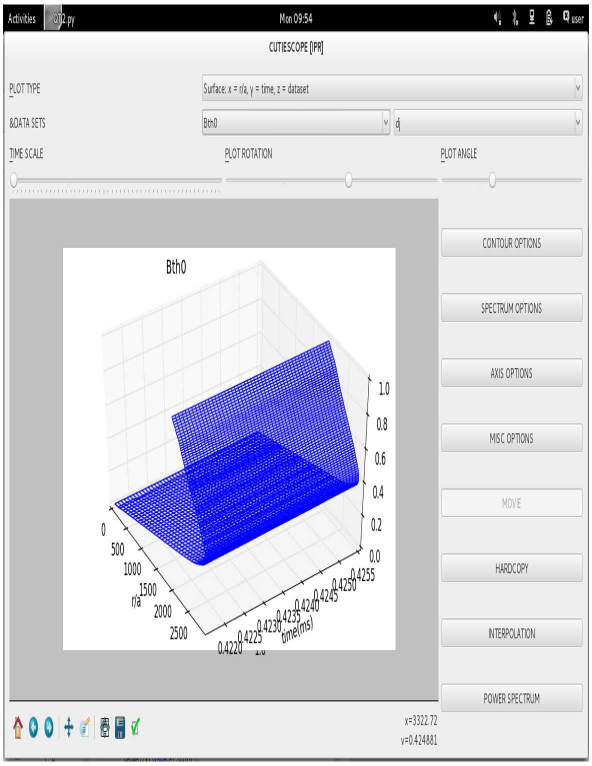

Figure 5.10: Plot rotation 1

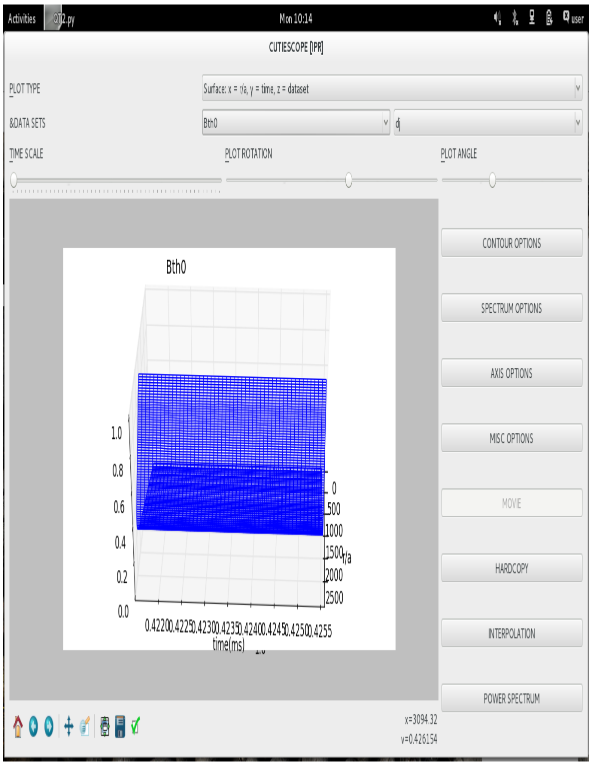

Figure 5.11: plot rotation 2

Provide means to generate animation for plot

Few plots are plotted on different axes parameters assuming a fix instant of time. These plots change as the time instant changes. The user needs to analyse plot while changing time instances. For this purpose movie feature has been added to the system. This option provides animated view of the plot. This option aids the user to observe changing plots with changing instances of time. This option is provided for generating movie for showing the plot with varying time frame. Such movie plot helps in to give a live experimental feeling with desired results.

Power Spectrum for plot

For fixed set of frequencies defined the power of different parameters can be defined. So from any type of plot user can click on power spectrum button to observe changing power of the parameter.

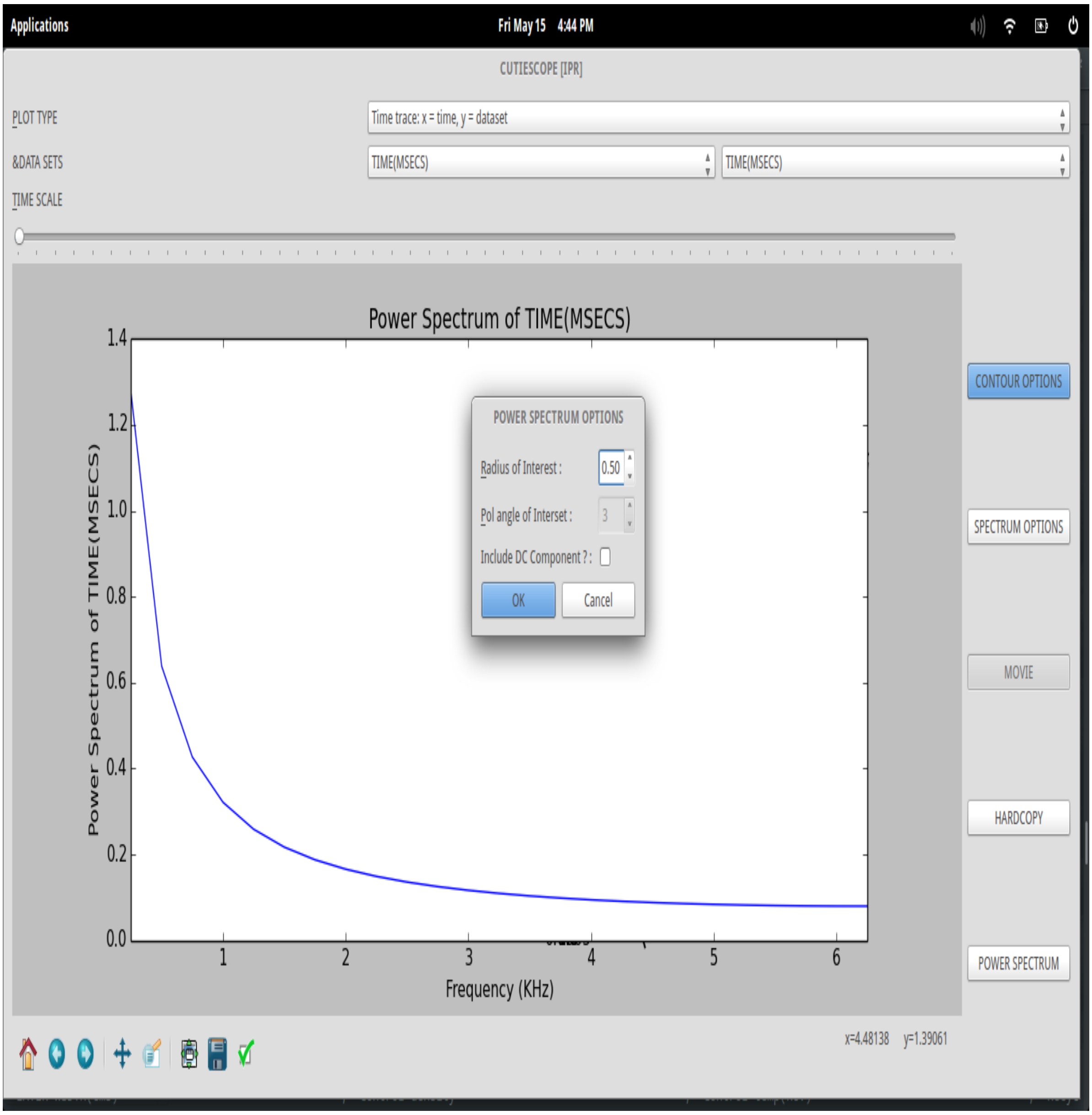

Figure 5.12: Power Spectrum for plot

Provide a user interface so that user may interact with the resulting plots

A user interface helps the user to interact and vary the parameters to observe the changing plot. The user can vary various effects on the plots. The system gives pan and zoom facility to interactively observe plot minutely.

Chapter 6

CONCLUSION AND FUTURE SCOPE

Nuclear fusion is a ray of hope for the future energy resource. Coalition has been formed among the nations to draw energy from nuclear fusion. This process is not easy as numerous instabilities being generated throw a spanner in the process. The CUITE code helps in the study of the instabilities causing hindrance to nuclear fusion. The purpose for these instabilities need to be studied in varying time scale and conditions. In order to facilitate these studies the application has been developed. The application processes the CUTIE code results in form of visual plots with various effects to thoroughly study the instabilities. Considerable amount of time was spent in understanding the need for generation of the CUTIE code and the difficulties faced in analysis of the instabilities of the tokamak. The problem of studying these instabilities of analysing the results of the CUTIE code can be resolved by providing visual effects of the changing parameters in the tokamak. In order to aid this visual sense of the CUTIE code concept of plotting was developed. The application under consideration automatically generates the plots adding various additional effects for the ease of the scientist.

Considerable amount of time was spent in reading the dump files and extraction of important data necessary for analysis. The techniques for visualization to be incorporated necessary for the user have been identified. Based on these techniques the extracted data has been mapped to show the data in form of graphical plot. The features necessary for the user to be applied on the plot of detailed analysis of the graph have also been implemented. Thus a complete package for the user to analyse the tokamak instabilities has been prepared. The system developed is open source and satisfies all the requirements for the tokamak visualization. The constructed application acts as a small clearance in the roadblock of the path of the nuclear fusion.

The present system developed can be enhanced by providing facilities of interpolation on axis,applying logarithmic scale on the axes,changing axes title. Visual enhancement by changing background and foreground color interactively.

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