Development of a Web Application: A HVRL Thermal Analysis Software

by

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Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

at the

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June 2003

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ABSTRACT

In this thesis, I describe the development of the Thermal Analysis Software for the High Voltage Research Laboratory at MIT. The goal of the Thermal Analysis Software is to provide a means to monitor and analyze valuable infrastructure like transformers.The civil and electrical engineering tasks, which have been done by very traditional ways, can experience a revolution when those jobs are combined with information technology. For example, maintaining infrastructures has been one of the main tasks in engineering. Maintenance and rehabilitation (M&R) should start with measures of performances of the infrastructures. However, the traditional M&R has something to be re-considered. First of all, measuring the performance cannot be real time. The conditions of infrastructures are changing, but all we can know by a traditional measure of performance is the condition at the time that was monitored. We are not able to be sure that the infrastructure is safe now, based on the past data. The second thing is monitoring a dangerous infrastructure traditionally can bring disaster that can harm inspectors fatally because most of jobs are done in-person, inside or around the potentially risky infrastructure. Another thing is financial aspect. The older infrastructure has the more things to be monitored more often.

If we depend on only labor of human, the older infrastructure means the higher expense on the M&R.

In this point, the advance of information technology can be the solution for those problems. Modern communication technology is using millisecond or even smaller one as unit, so it is real time even though there are some delays on network, especially comparing the measurement done by person. The other advantage of using information technology for monitoring infrastructure is that we do not need to worry about the safety of workers. Once installed monitoring system will send data to the workers who are working in the safe office, so no one needs to enter the dangerous infrastructures. As mentioned before, already installed monitoring system, which uses modern information technology and communication skill, does not need spend fund for labor, and gives data as often as necessary. That means there is only low extra cost for measuring infrastructures. With these reasons, it would be very useful if we were able to come up with a strategy for predicting the level of service or hazards.

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Title: Senior Lecturer, Department of Civil and Environmental Engineering

ACKNOWLEDGMENTS

I owe special thanks to my Thesis Advisor, Dr. George Kocur, who has contributed a lot to this project with his valuable advice, support and opinions. His experience and knowledge about the IT industry were an invaluable resource, which helped me during my project work. I am grateful for all the time and efforts he has dedicated into this project.

I would like to express my gratitude to the Department of Civil and Environmental Engineering and Dr. Eric Adams for providing me the financial support.

I would also like to thank Prof. John R. Williams for helping me in exploring my interests and giving my thoughts a definite direction.

I would like to express my deepest gratitude to Dr. Chatham Cooke and Timothy Cargol at the High Voltage Research Laboratory at MIT for giving me this interesting and challenging project.

Finally I would like to thank my family and close friends, whose support and love kept me going through the year. I would like to thank my parents for their invaluable love and support and having faith in me. I especially want to thank Navpreet Parmar, Ghulam Mujtaba Sheikh, and Nimisha Rao for keeping me sane, for always having faith in me and for listening to me.

NIMRAT BHATTAL

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1. Introduction

1.1. Overview

The process of cooling an element is particularly relevant in High Voltage Research as a great deal of heat is generated in large electrical elements. Frequently, the thermal stress placed on an element governs its electrical load capacity. Consequently, the HVRL at MIT would benefit from software that would take data from thermal sensors on an array and provide a way of making meaningful analysis of what is occurring inside an array. In this, the advanced information technology can be the solution for the problem stated above. Modern communication technology is using millisecond or even smaller one as unit, so monitoring of infrastructure can be done real time even though there are some delays on network, especially comparing the measurement done by person. The other advantage of using information technology for monitoring infrastructure is that we do not need to worry about the safety of workers. Once installed monitoring system will send data to the workers who are working in the safe office, so no one needs to enter the dangerous infrastructures. As mentioned before, already installed monitoring system, which uses modern information technology and communication skill, does not need to spend funds for labor, and gives data as often as necessary. That means there is only low extra cost for measuring infrastructures. With these reasons, it would be very useful if we were able to come up with a strategy for predicting the level of service or hazards.

1.2. Purpose

The following document provides a brief description of Thermal Analysis Software Services to be designed for the MIT High Voltage Research Laboratory. The current document provides the system requirements for implementing the system and an estimation of the size of the work to be completed.

1.3. Scope

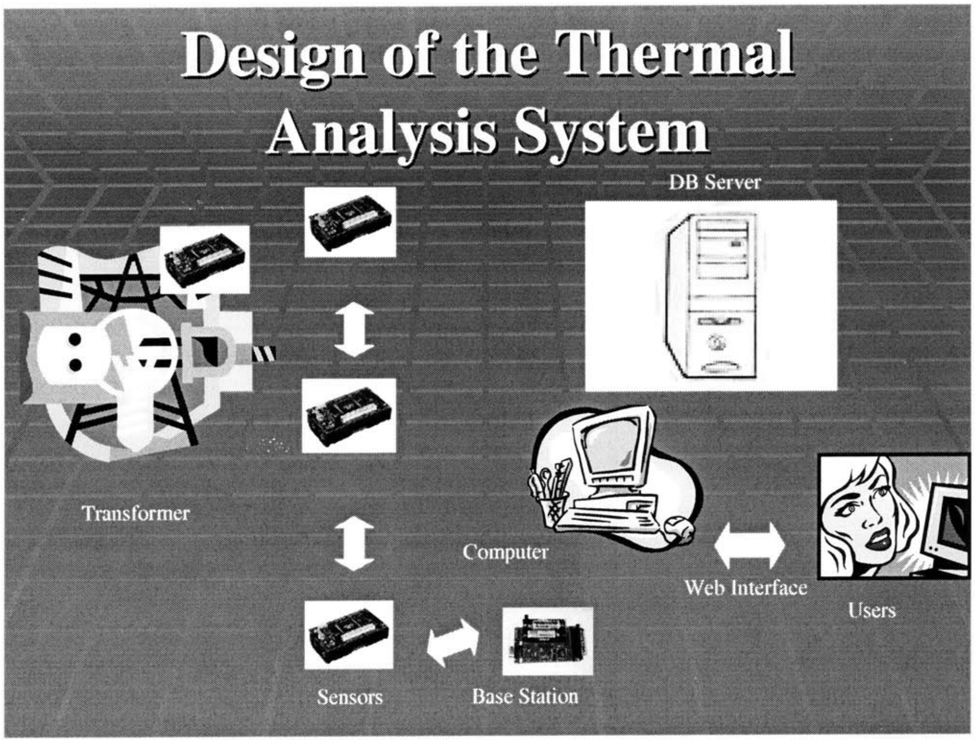
The HVRL thermal analysis software is composed of a group of web application and database elements. These elements are all integrated behind a robust, web graphical user interface. The system will be designed to complete following the tasks:

- Set of applications and web services to analyze data sensed from a planar and a cubic thermal array surrounding variable internal heat sources.
- The GUI to provide the user with information about the history, context, and applications of the HVRL with the focus on the thermal analysis methods described in this document. The GUI is detailed in the following sections.
- Develop a sub-set of database tables to support the web features: Relational database to store and retrieve data from existing data provided as well as adding incoming live data.
- The software provides tools for graphing the data as isothermal contours, generating topological thermal and heat flux maps of the array.
- The total heat loss over time will be calculated using the sense data to provide an estimation of the cooling features of the process.
- A slide show/animation of the contours will be created to provide a graphical interpretation of the change in temperature and heat flow over time.

2. System Features

2.1. Schema of the entire System

The system layout is shown in Fig.1. Sensors, which are connected to motes, get data from the Cube Box representing a transformer. This data is transmitted to a base station which is another mote running a program to collect data. The base station has a connection to a computer that runs a TCP server for forwarding this data. A client program that publishes this data to a web server, as well as archives this data, then reads the data. Even though we are currently retrieving data from the database, real time results can be published using a web service, which can be shown to the authenticated clients.



Design of the Thermal Analysis System

Figure1: Schema of the HVRL Thermal Analysis System

2.1.1. System Architecture

The data that the sensors collected are forwarded to the base station. The base station (one of the motes) in turn is connected to a computer through a serial port connection. Through the program, SerialForward, a TCP server is run in this computer ready to serve real data to clients. A client connects through a direct TCP/IP socket connection and forwards the data to a central web Server. The central web server has an application that constantly archives the data in SQL Server database. When an authorized user requests some archived data through the web UI, a new thread is spawned off (treating the database like a client). The data base retrieval is done using Stored SQL procedures, for faster performance. If any authenticated user requests real time data, then a new thread should be launched that publishes real time data through a web service. The input to the web service would be an array lists of data readings. Currently, this feature has not been implemented in the project as it was beyond the scope.

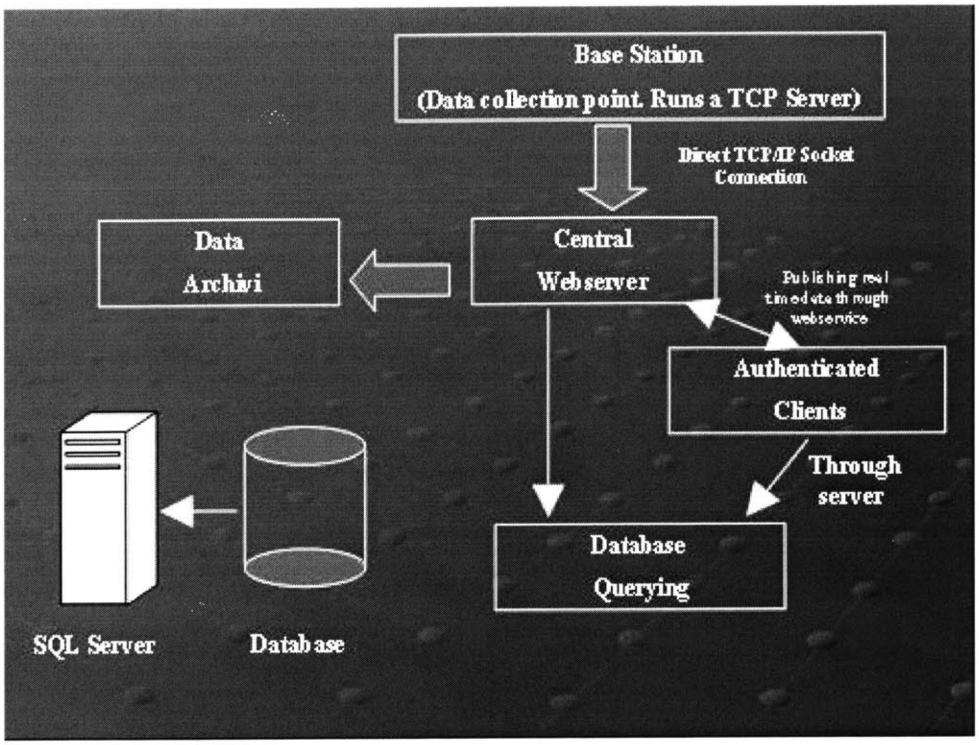

Base Station
(Data collection point. Runs a TCP Server)
Direct TCP/IP Socket Connection
Data Archivi
Central Webserver
Publishing real time data through webservice
Authenticated Clients
Through server
Database Querying
SQL Server
Database

Figure 2: System Architecture

2.1.2. Requirements for the Network

Wireless: Wireless networks are clearly more convenient than their wired counterparts. Moreover in harsher and crowded conditions, a source of power required by the wired networks may not be available and wireless networks might be the only solution.

Intelligent autonomous units: The individual nodes that comprise the sensor networks should ideally be capable of doing some computations and taking certain decisions with the second data on hand. Besides they should be able to do so without directions from a certain unit. This capability would be necessary if the networks have to be dynamic rather than static and change their behavior in accordance with the conditions on hand.

Low Power Consumption: Power availability would be the main concern in sensor networks and it is necessary that the individual units are capable of adjusting their power consumption in response to requirements.

Physically small size devices: Almost entire network system will be exposed to the public place, so big devices can make many trouble. Therefore to protect the system, and also not to disturb infrastructure-users, physically small size should be main requirement.

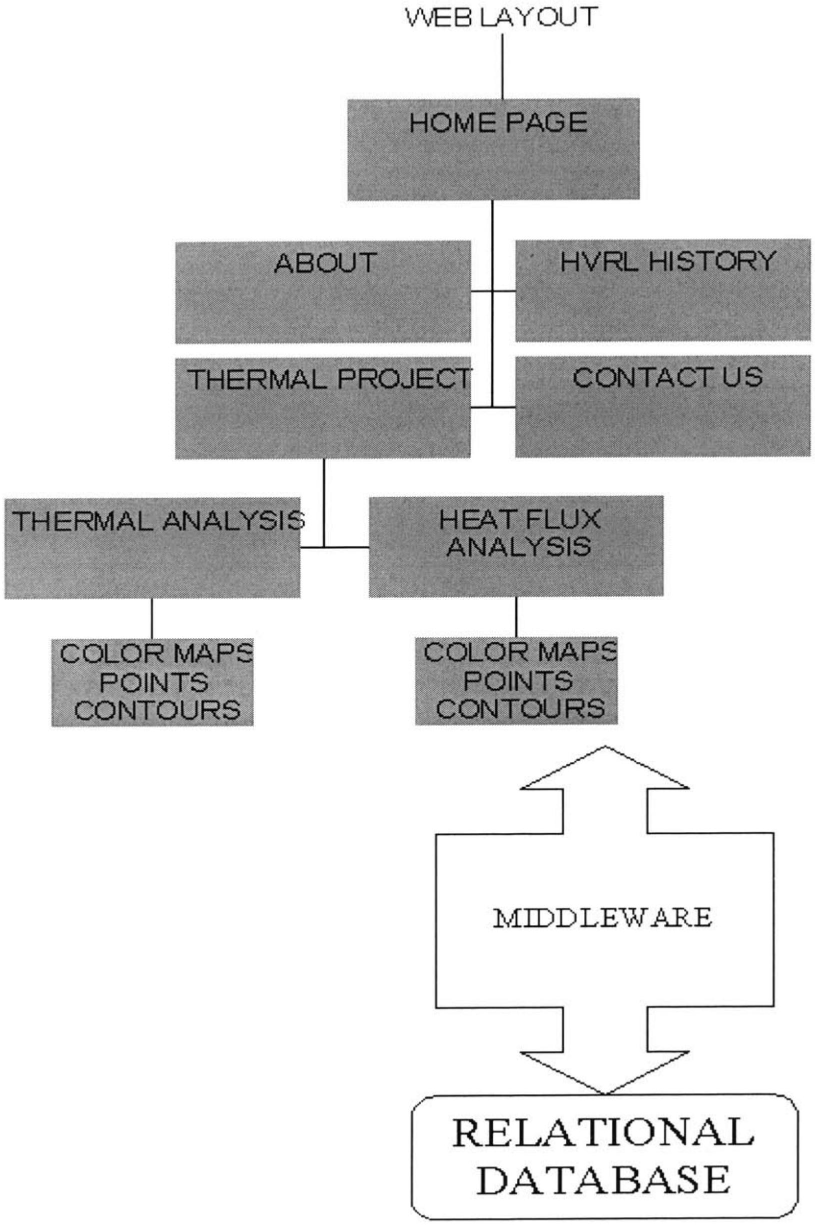


Figure 3: Overview of the HVRL Analysis Software System

2.2. Database Tables

Session_Header Database: Provides a parent class representing a *data-monitoring event.* Each data-monitoring event is composed of many *data* entries for sensor making readings

- Data_num (PK): Provides the primary identification of each data-monitoring event.
- Time_stamp: The time stamp according to the device data is coming from for each data monitoring event
- Tini_id: The unique Ethernet address of the device data is coming from
- SW_Version: Version of the software used to monitor the event.
- AA: Field that defines the type of monitoring event. For instance, AA= 10 stands for oil test, AA= 20 stands for thermal monitoring event (used in the data this system analyzes).
- Create_date: Database time at which the data row was added to the database.

Data Database: This will keep track of the incoming data from the sensors. Each data entity represents one sensor reading in a sensing event.

- Row (PK): This is a unique number, which is the ID for each Data entity created.
- Data_num (FK): Provides the identity of the data-monitoring event to which the data point belongs.
- BB: It is an integer that specifies the physical layout of sensors. BB = 8 corresponds to the cubic array analyzed here.
- CC: It is the face number of the thermal box.
- DD: This specifies the x-coordinate of the sensor location.
- EE: This specifies the y-coordinate of the sensor location.
- Data_Val: This is the value of the data from each sensor.

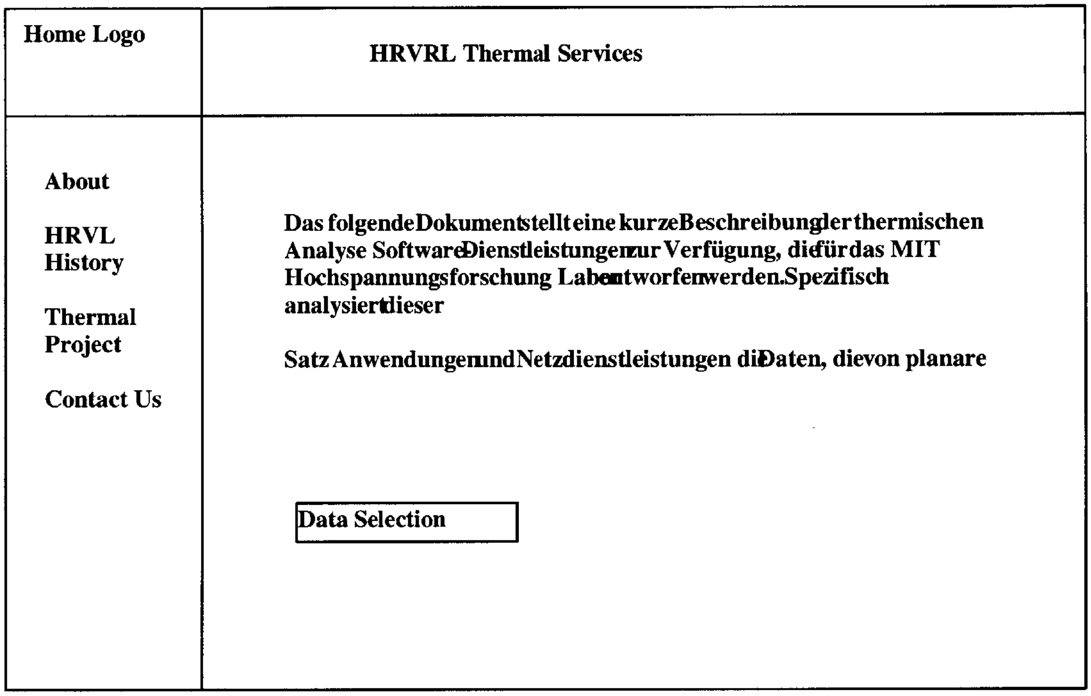
Note: We estimate that another set of databases might be created (between 1 and 2 more) in the course of developing the system.

For this project, no major changes would be made to the database. Data filtering for errors would be introduced to filter out-of-range observations and missing data (taking average of neighboring data points).

2.3. Web Features

2.3.1. Home Page

The first page viewed by the user is seen in a small schematic in the figure below:



Das folgende Dokument stellt eine kurze Beschreibung der thermischen Analyse Software Dienstleistungen zur Verfügung, die für das MIT Hochspannungsforschung Lab entworfen werden. Spezifisch analysiert dieser

Satz Anwendungen und Netzdienstleistungen die Daten, die von planare

Figure 4: Home Page for the website

The homepage (Fig .1) includes a navigation scheme to the left with buttons to travel between common tasks and frequently visited sites. It will have the hyperlinks to the following web pages:

- **About**: Brief description of the company trajectory, the services NPD provides and their target market (this text and logo design will be provided by NPD) of about one paragraph.
- **HVRL History**: One paragraph Brief history of the High Voltage Research Lab with photo.
- **Thermal project**: One paragraph Background and information about the thermal project with photo.

- **Contact Us**: This hyperlink would include the contact information provided by HVRL for their guests.
- **Staff Login and Password**: The company employees would be assigned login and password, which they can use to enter the employee web page.
- **Data Search**: This would link to a search interface that would allow the user to compile a data set of thermal readings. The range of data that can be searched is limited.

All the web pages would have links to go back to the main page.

The default for the main view is a brief welcome and description of the site. This main page can always be accessed by clicking the home logo in the upper right hand corner.

2.3.2. Data Search

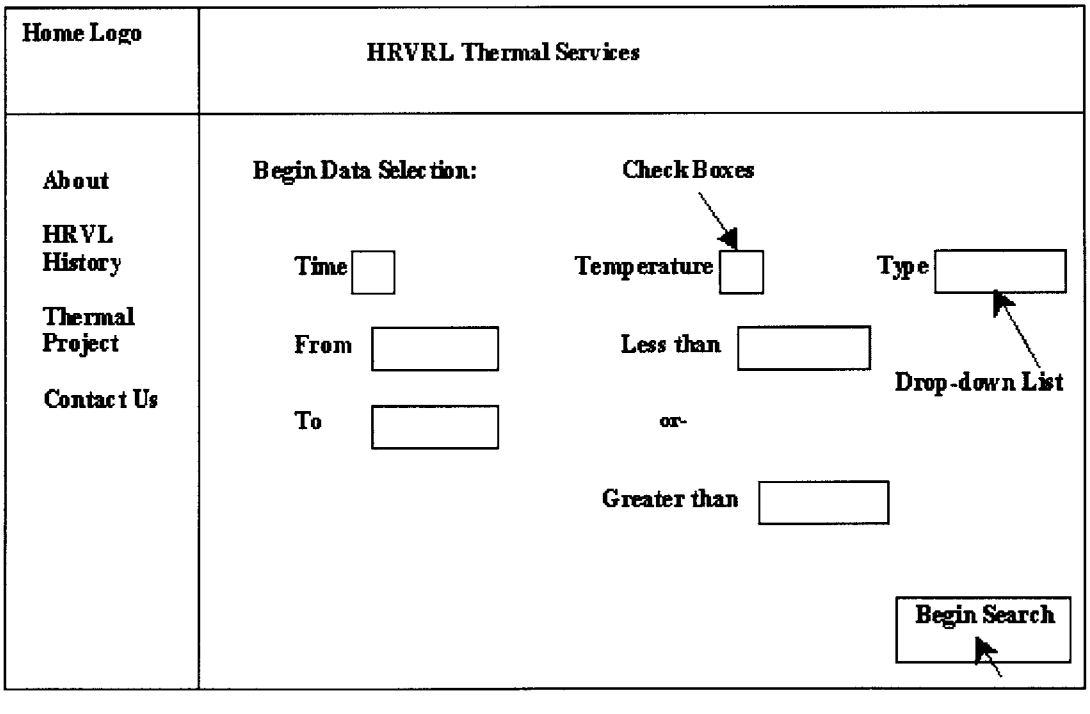


Figure 5: Data Search

The searching feature allows for the ability to search based on a range of times, including the present, as well as by a range of temperatures, including infinity as lower and upper bounds (as long as an upper and lower bounds is defined, respectively). The search feature would also include the type of experimental apparatus: thermal box, cylinder, or plate (not shown in the figure).

The searching panel is composed of a check box to select between temperature and time searches, with list boxes for users to select dates, temperature ranges, and a drop-down list to select the type of apparatus. Finally, a "Begin Search" button allows the user to execute his query.

2.3.3. Data Set Rendering

Once the "Begin Search" button is clicked the following page would be displayed:

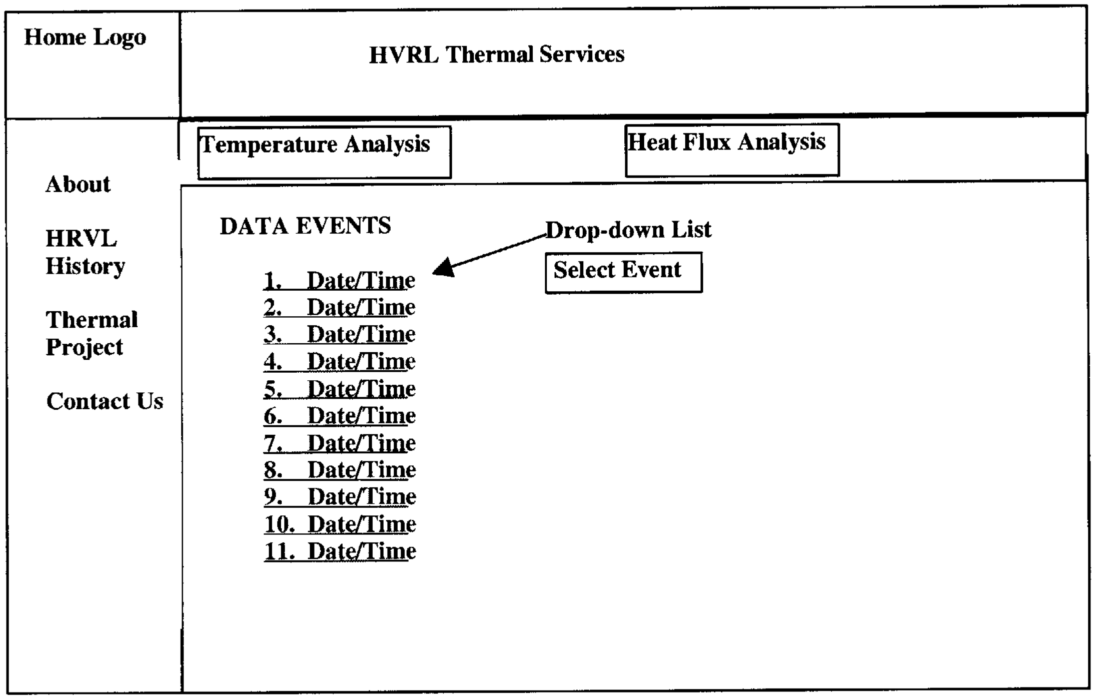


Figure 6: Data Set Rendering

After the query is executed, the main view is updated to include the data set and a text description (Fig.5) of the analysis tools listed in folder-type buttons above the main view, namely,

- Temperature Analysis
- Heat Flux Analysis

It would also include a drop-down list of data events for the user to select any particular data event for analysis.

Once the user selects a data event from the drop-down list and clicks on any particular analysis type, the view buttons would be made available on the next page along with data for all the 105 data items corresponding to the selected data event.

The above views would be designed for sensors uniformly spaced over the thermal box, but the algorithm would be written to be able to run for non-uniform spacing. All algorithms would be written using historical data for first spiral of development process and would be linked to live incoming data in the second spiral.

2.3.4. Data Display

The view buttons allow the user to choose the types of display they want to use to view the data items. Different view types would be:

- **Point**: This would allow the user to view points as an array of points on a 2-D surface.
- **Contours**: To let user view data as discrete contours, or smooth contours over selected time range. Contours can be straight sharp lines for first spiral model of development process. The second derivative curve smoothing of contours can be included in the second spiral of development process. Contours would be made on the 2-D model for first spiral.
- **Color Maps**: To let users view data as color segments to fill areas between contour lines. The range of colors can be auto range as well as manual color options. The color pixels can be of any resolution.
- **Heat Flux (only) calculation**: This would provide a list of heat fluxes of each surface of the device.
- Once the user selects the view type, the page is updated with the selected display view (Fig.6). The navigation panel is recessed so that the maximum graphing space is available. The user can refine his data search by selecting the option of "Search" from the drop-down list.

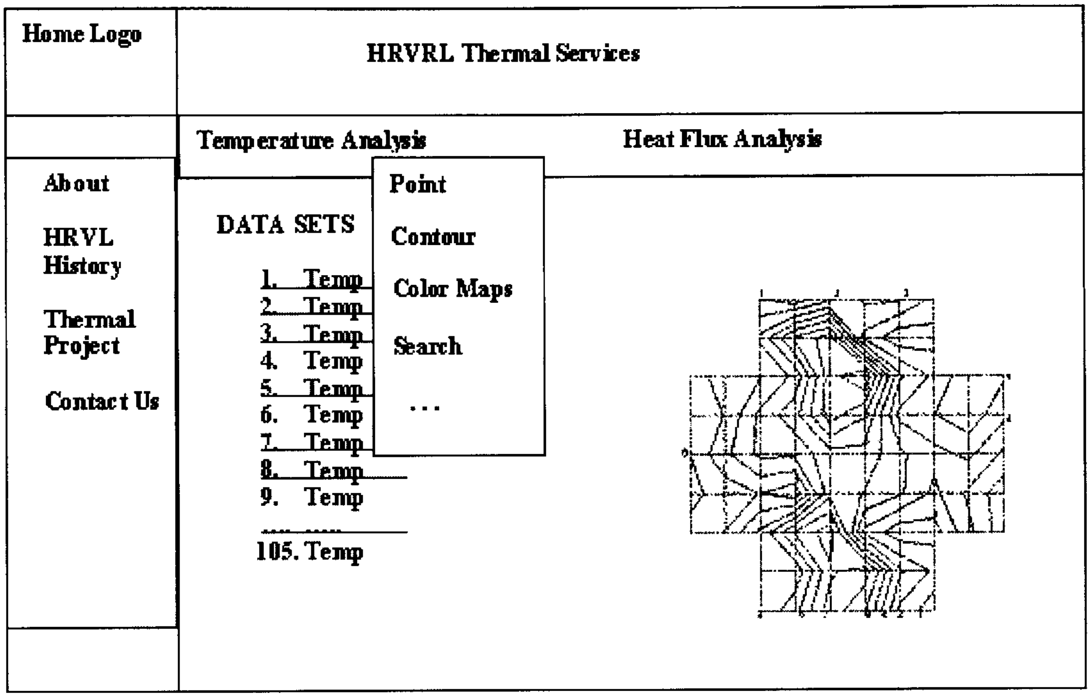


Figure 7: Discrete Contour Plots

An ***Error Message*** would be displayed in the case of a failed query or procedure in the text/graphic panel of the main view.

2.3.5. Data Calculation

While display of both the temperature (C) and heat flux (W/cm^2) can be rendered, a calculated value for heat flux can be generated by selecting the "Calculate" option for the "Heat Flux Analysis" drop down menu. This would display the heat flux on each of the sides of the device, as well as the sum of the heat flux for all known surfaces as seen in Fig. 8. The heat flux would be measure considering steady state i.e. assuming no variation over time for the first spiral of development process.

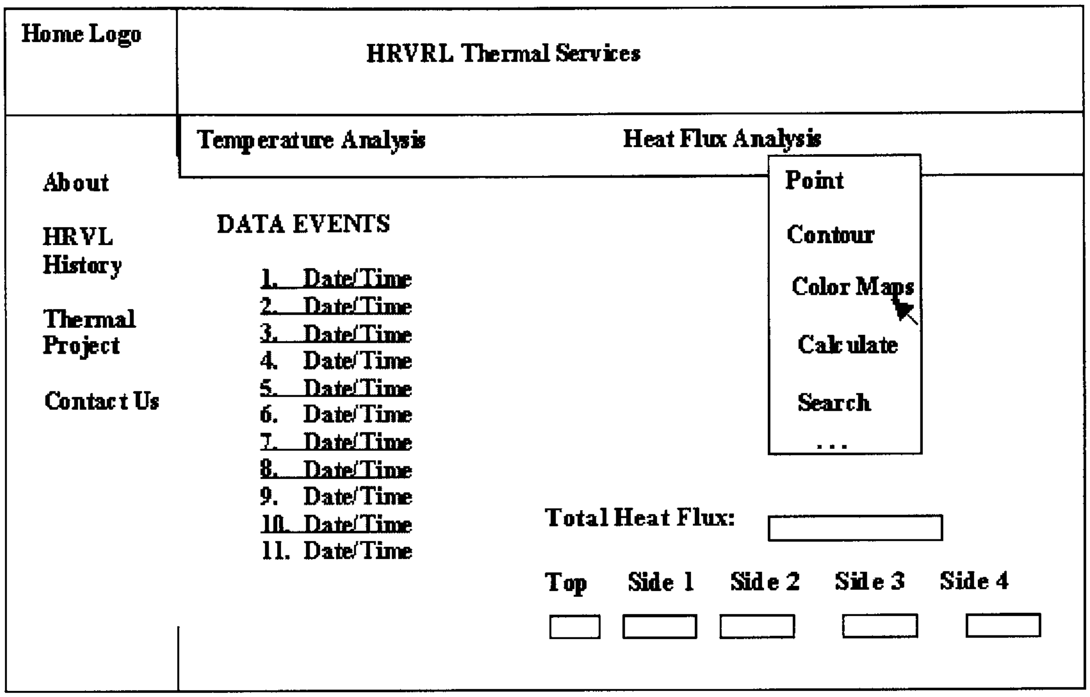


Figure 8: Heat Flux Calculation

2.5 Assumptions

The existing guest users already know their user name and password or the company would provide them with this information.

The website would not allow the guests to update their information. They would have to call the HV at the address provided in the "Contact US" given on the web site.

For security, only one employee (system administrator) would be made responsible for updating and adding information and providing other users with login and passwords.

2.6. Size Estimation of the Project

To estimate the size of the system, we count function points:

Web inputs:

Low complexity: Login- staff, staff database access 'home', data set rendering, heat analysis, temperature analysis

High complexity: home page, search page

Web outputs:

Low complexity: about, contact us, HVRL history, Thermal Project, Medium complexity: 6 queries to calculate total heat flux as well as heat flux for each of 5 faces of the box. High complexity: contours (animate and discrete), color maps, and points for both temperature analysis and heat flux analysis, windows authentication.

Web inquiries:

High complexity: Begin search

We estimate 3 tables for now. We assume 2 are medium complexity for now and 1 of high complexity as the one including heat flux.

Thus, our function points are:

Program unit	Low	Medium	High
Web inputs	5 x 3 = 15	0	2 x 6 = 12
Web outputs	4x 4 = 16	6 x 5 = 30	9 x 7 = 63
Web queries	0	0	1 x 6 = 6
Database tables	0	2 x 10= 20	1 x 15= 15
Total			177

Table 1: Function Points for Size Estimation

Estimate lines of code:

Program unit	Tool	Lines/function point
Web inputs, outputs, queries	Visual Studio.NET	25 (code generation)
Windows inputs, outputs, queries	C#	30 (code generation)
Database	SQL Server 2000	40 (code generation)

Table 2: Estimated Lines of code

The total lines of code are approximately 5000.

Estimate person months:

Using table 8-10, Nominal Schedules for Systems Products, the lowest entry is 10,000 lines of code, with 6 schedule months and 9 person months. With a system 46% this size, the person months will be less than 46% of 9 months. An estimate of 40% is reasonable or about 3.6 person months.

Estimate schedule months:

Using table 8-10, the 6 schedule months for 10,000 lines will be reduced for a project of 4,600 lines, but not proportionally. Using an exponent of 0.4 (table 8-7), a project that is .46 of the effort should take about $(.46)^{0.4}$ time, or about 0.73 the time. The 6 schedule months thus become about 4.5 months.

Team size:

With 3.6 person months over 4.5 schedule months, the average team size is about .8 persons.

3. Data Modeling

The data modeling process for the HVRL Thermal Analysis Software has been simplified because a basic, data-driven system is already in place implemented with MS SQL Server 7 and ASP. The HVRL software is designed using ASP.NET with C# code-behind, server-side scripts. ASP.NET provides optimized database connection classes for SQL Server 7 & 2000. The searches that will be performed already run quickly on the current server, and the data models discussed here do not add large increases in complexity.

However, an idealized data model has been presented to show some steps that would ensure better data integrity in the system. Finally, a recommended update model has been provided to show changes that could be made, if all of the currently proposed features (especially password – protected login) were required.

3.1. Implemented Data Model

The currently implemented, physical database model is show in Fig.8 below.

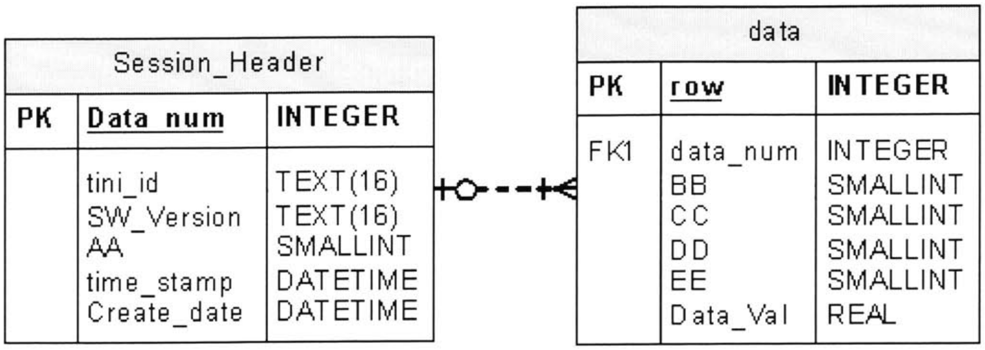


Figure 9: Implemented HVRL Data Model

Each of these tables and its attributes are described as follows:

Session_Header Table: Provides a parent class representing a *data-monitoring event.* Each data-monitoring event is composed of many *data* entries for a sensor making readings

- Data_num (PK): Provides the primary identification of each data-monitoring event.
- time_stamp: The time stamp according to the device data is coming from for each data monitoring event
- tini_id: The unique Ethernet address of the device where data originates.
- SW_Version: Version of the software used to monitor the event.
- AA: Field that defines the type of monitoring event. For instance, AA= 10 stands for oil test, AA= 20 stands for thermal monitoring event (used in the data this system analyzes).
- Create_date: Database time at which the data row was added to the database.

Data Table: Each Data entity represents one sensor reading in a sensing event.

- row (PK): This is a unique number, which is the ID for each Data entity created.
- data_num (FK): Provides the identity of the data-monitoring event to which the data point belongs.

- BB: An integer that specifies the physical layout of sensors. BB = 8 corresponds to the cubic array analyzed here.
- CC: The face number of the thermal box.
- DD: The x-coordinate of the sensor location.
- EE: The y-coordinate of the sensor location.
- Data_Val: The value of the data from each sensor.

Problems with this model include a lack of enforced referential integrity (data's attribute data_num, a functional key, is allowed to be null, although the relationship is identifying), and a potential for undocumented or unidentifiable values as attributes like SW_version, AA, and BB can potentially have multiple values corresponding to specific description of the entity in which they appear, stored outside the database.

3.2. Idealized Data Model

The idealized model is shown in Fig. 10.

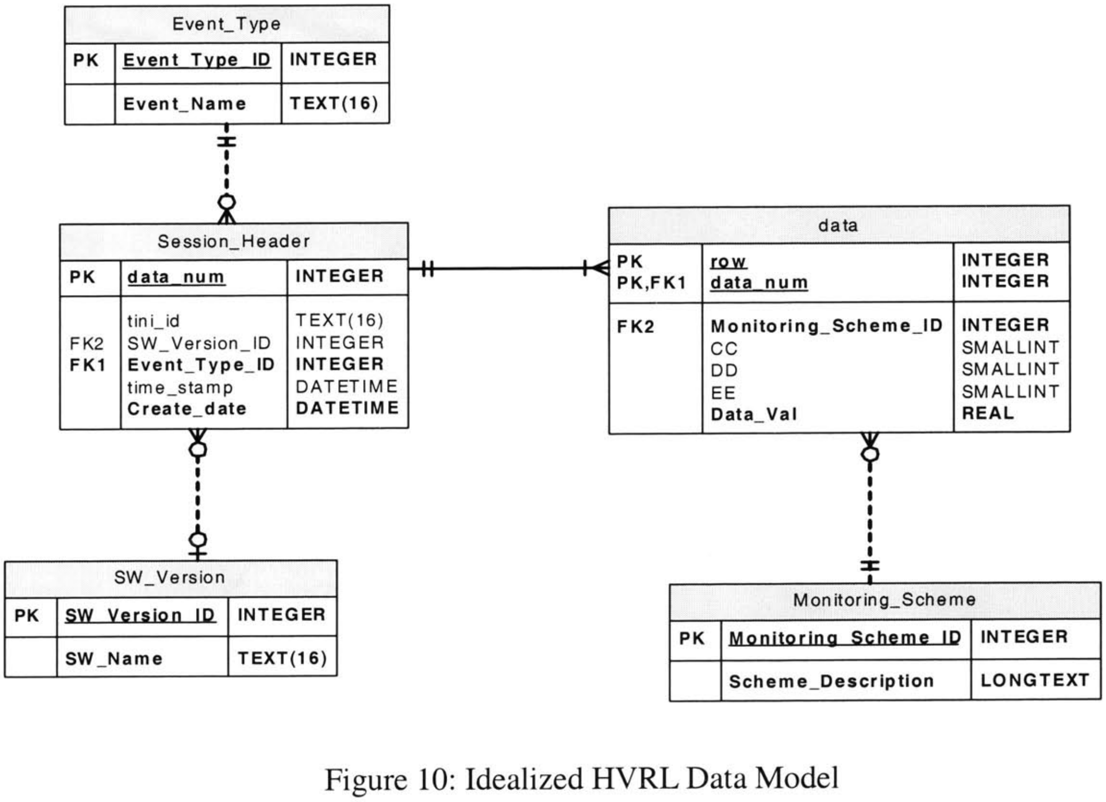


Figure 10: Idealized HVRL Data Model

A description of changes in the idealized data model is provided as follows:

Session_Header Table: Provides a parent class representing a *data-monitoring event*. Each data-monitoring event is composed of many *data* entries for a sensor making readings

- data_num (PK): Data_num changed to data_num to avoid syntactic coding error is applications consuming the database system.
- SW_Version_ID (FK2): Provides an ID to link to a table of all known sensor version software. This FK is not required so that experimental sensing systems can be configured and various setups can be stored before any system goes online. Because several software types may be used during this phase of system development, SW_Version_ID would not be a required element.
- Event_Type_ID (FK1): Field that defines the type of monitoring event. For instance (replaces AA). It provides a link to all known types of monitoring events. Because data is useless without knowing the type of monitoring event/laboratory test the data originated from, this field is required.
- Create_date: This field is set to be required as transients are an integral part of all data analysis for this system.
- **Data Table:** Each Data entity represents one sensor reading in a sensing event.
- data_num (PK, FK1): Because each Data entities relationship with a session header is identifying, a data entity has a composite primary key consisting of both the row and data_num attributes.
- Monitoring_Scheme_ID (FK2): An integer that specifies the physical layout of sensors (formerly BB). This links to a table of all known physical layouts. Because data is useless without knowing the positioning and location of a sensor array, this field is required.
- Data_Val: The value of the data from each sensor. Data_Val is set to be required since it is the fundamental attribute in a sensing event.

Event_Type Table: This table provides a catalog of types of monitoring events (such as “thermal”, “oil test”, etc.).

- Event_Type_ID (PK): Provides a primary key ID attribute for all types of monitoring events.
- Event_Name: Stores the name of an event type.

Monitoring_Scheme Table: This table provides a catalog of sensing location and position schemes (such as “cubic array”, “roof array”, or “plate array”).

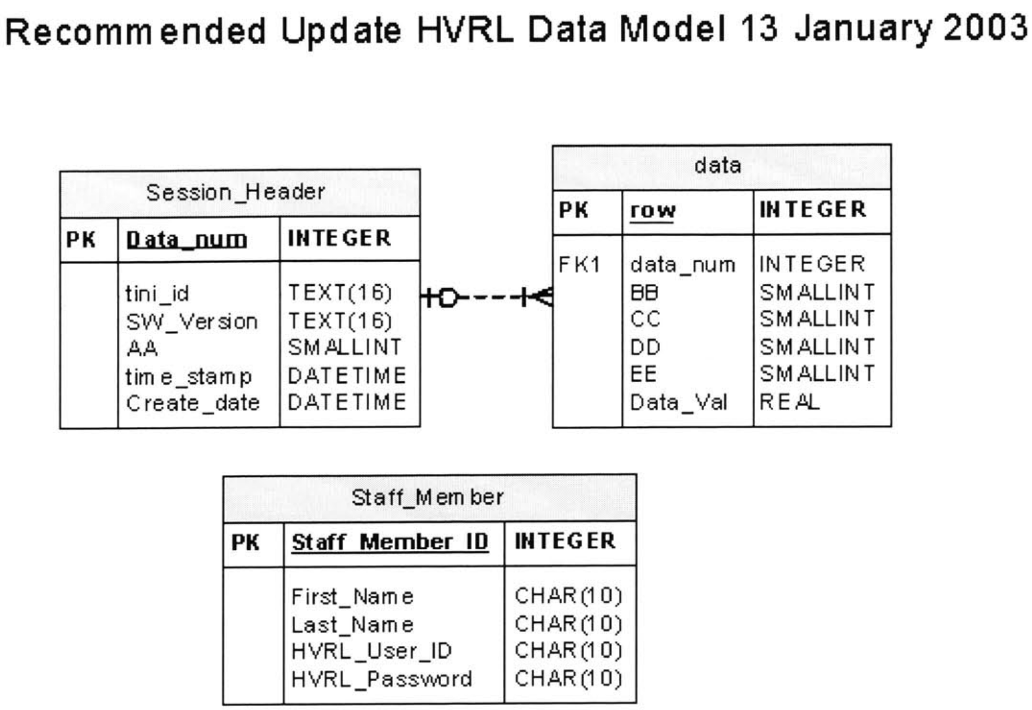
- Monitoring_Scheme_ID (PK): Provides a primary key ID attribute for all types of monitoring schemes
- Scheme_Description: Provides a field to enter a flexible description of a type of monitoring scheme.

SW_Version Table: This table provides a catalog of sensor software versions.

- SW_Version_ID (PK): Provides a primary key ID attribute for all types of sensor software.
- SW_Name: Stores the name of the sensor software version.

3.3. Recommended Update Model

This final data model shows the recommended updates for the HVRL database system. Rather than making changes to the model already implemented at HVRL the only additional tables suggested are those that would drive password – protected login to the HVRL site.



Session_Header

PK	Data_num	INTEGER
	tini_id	TEXT(16)
	SW_Version	TEXT(16)
	AA	SMALLINT
	time_stamp	DATETIME
	Create_date	DATETIME

data

PK	row	INTEGER
FK1	data_num	INTEGER
	BB	SMALLINT
	CC	SMALLINT
	DD	SMALLINT
	EE	SMALLINT
	Data_Val	REAL

Staff_Member

PK	Staff_Member_ID	INTEGER
	First_Name	CHAR(10)
	Last_Name	CHAR(10)
	HVRL_User_ID	CHAR(10)
	HVRL_Password	CHAR(10)

Figure 11: Recommended Update HVRL Data Model

4. UML Activity Process Model for HVRL Thermal Software System

The following processes occur to run an analysis on data in the suggested HVRL Thermal Software system:

1. The user can choose to login to the system as a staff user.
2. The optional login is validated by the server. If the validation fails, the login is denied and the user is given the choice to resubmit an ID. The user can choose to return to the starting search page.
3. The user submits a search.
4. The HVRL Analysis system validates the search. If the validation fails, the user may redo a search or choose to exit.
5. The dataset of events falling within the specified query is returned. The user then specifies the type of analysis and data event to process.
6. The user then chooses the display of analysis. The user can modify the current search or return to the original search.

7. When the user chooses not to supply requests any longer for search modification or display, the process is ended.

The UML Activity Model for these processes is shown in Fig. 12.

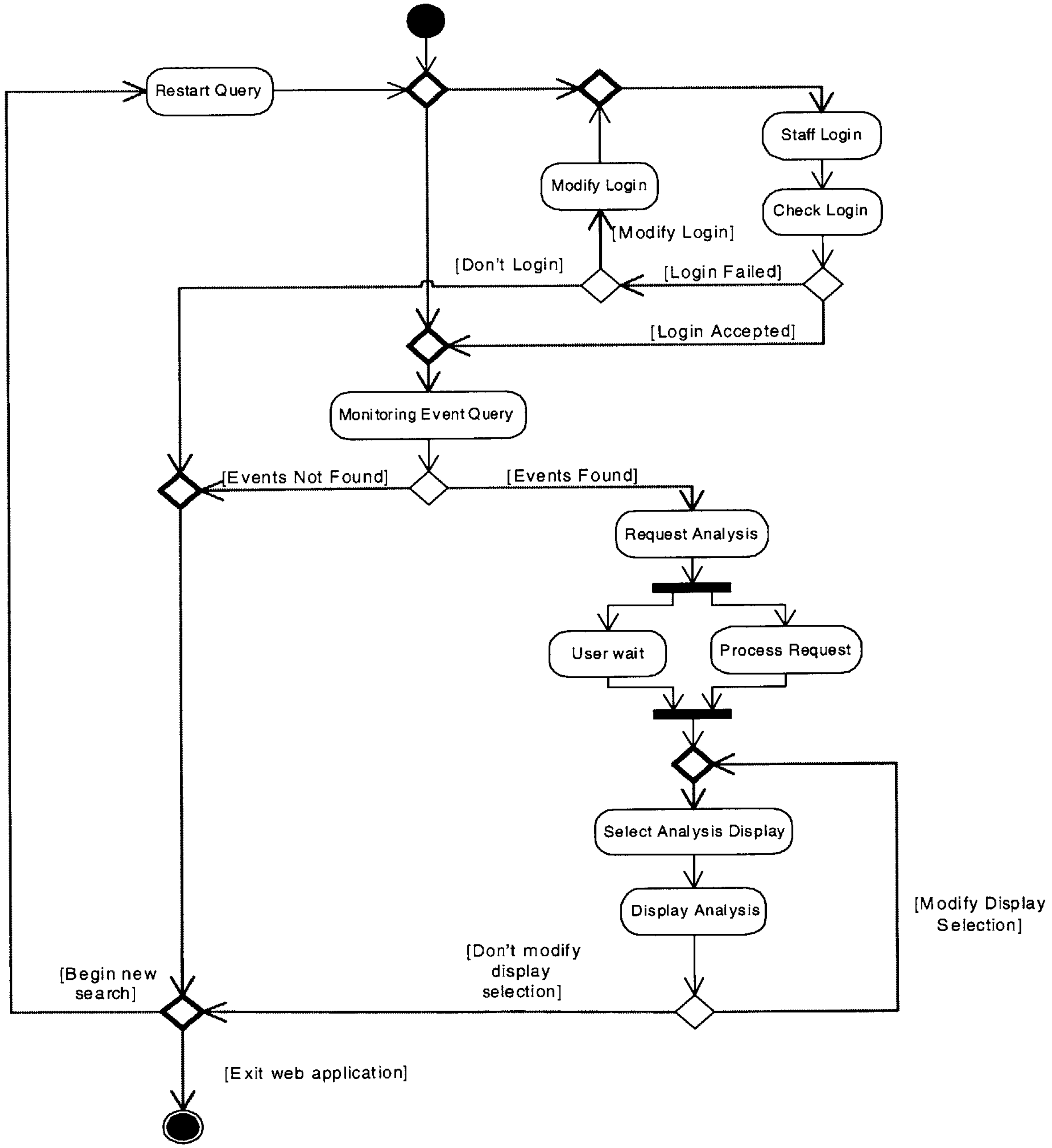


Figure 12: UML Activity Process Model

5. HVRL Analysis Software Use Case Diagrams

5.1. Actors

Primary Actor: Staff User

Variations: User is:

Guest

Client

Goal:

Search Sensor data and analyze it.

5.2. Use Case Diagram for the HVRL Analysis Software

The use case diagrams of the entire HVRL Analysis software can be generally illustrated in Fig.13:

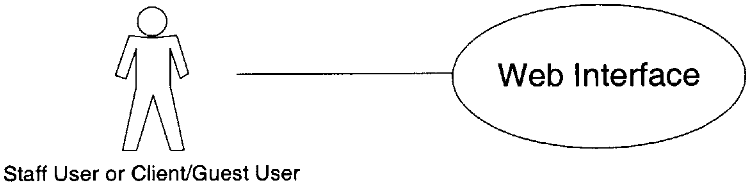


Figure 13: Use Case Diagrams for HVRL Analysis Software

5.3. Web Interface Use Case Diagrams

The use case diagram for the web user interface is shown in Fig. 14.

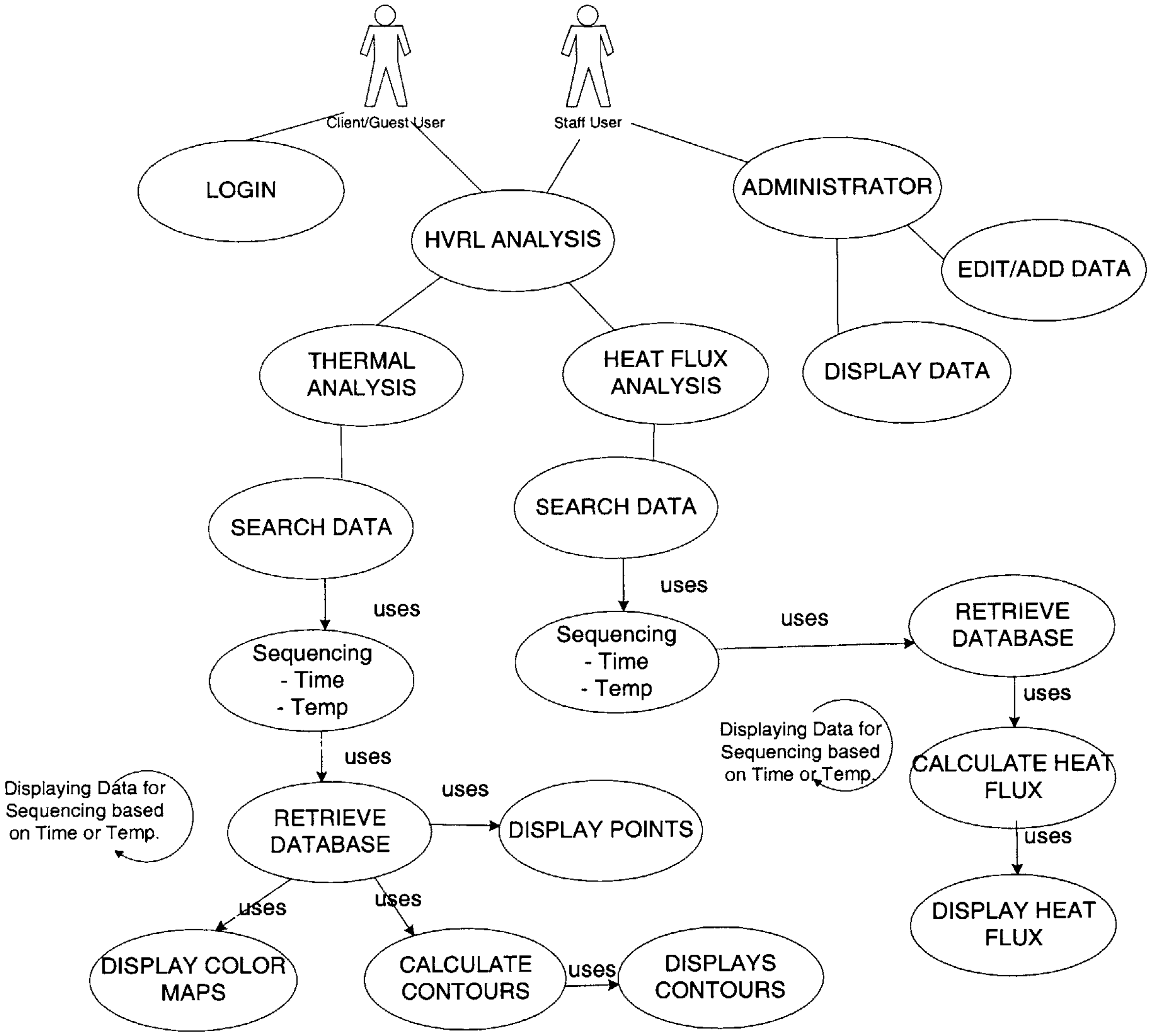


Figure 14: Web Interface Use Case Diagrams

5.3.1. Login use cases

The system starts with this page, which verifies the user before starting the system.

Login:

This use case is for the existing user to log into the system

- The user enters his login name and password
- The system checks if the login name and password are correct again the database.
- If yes, the system allows the user to access the data analysis page.
- If not, the system displays the error page and lets the user enter the data again.

Assumption:

The user has a login name and password for accessing the system.

5.3.2. Data Analysis use cases

This set of use cases allows the user to do analysis on selected data sets. A search page is displayed for the user to select various parameters of search like the temperature range, data range, and type of array.

Temperature Analysis:

This use case allows the user to retrieve data from the database and perform thermal analysis

- The user selects the date range for the search.
- The user selects the type of sensor array i.e. cubic or planar.
- The user specifies the temperature range.
- The user also selects the analysis type.
- The system retrieves data sets from the database by using the Retrieve Database use case and displays them.

Heat Flux Analysis:

This use case allows the user to retrieve data from the database and perform flux analysis

- The user selects the date range for the search
- The user selects the type of sensor array i.e. cubic or planar.
- The user specifies the temperature range.
- The user also selects the analysis type.
- The system retrieves data sets from the database by using the Retrieve Database use case and displays them.

Retrieve Database:

This use case retrieves data from the database and displays them to the user

Given the selected data and temperature range the system retrieves the data from the database

- The system returns the following information to the user:
- The identity of the data-monitoring event to which the data point belongs.

- The time and date according to the device data is coming from for each data-monitoring event.

Assumptions:

The monitoring event for the specific date and temperature range exists.

The identity of the data-monitoring event is not null.

Display Points

This use case allows the user to view points as an array of points on a 2-D surface.

The user selects one data set from the search results displayed.

Given the above selection, the system displays the results as a point array on a 2-D surface.

Assumptions:

The monitoring event for the specific date and temperature range exists.

The identity of the data-monitoring event is not null.

Calculate and Display Contours

These use cases lets the user view data as discrete contours, or smooth contours over selected time range based on the algorithm developed to calculate contours.

The user selects one data set from the search results displayed.

Given the above selection, the system displays the results as contours. Contours can be straight sharp lines for first spiral model of development process. The second derivative curve smoothing of contours can be included in the second spiral of development process. Contours would be made on the 2-D model for first spiral.

Assumptions:

The monitoring event for the specific date and temperature range exists.

The identity of the data-monitoring event is not null.

Display Color Maps

This use case lets the user view data as color segments to fill areas between contour lines. The range of colors can be auto range as well as manual color options. The color pixels can be of any resolution.

The user selects one data set from the search results displayed.

Given the above selection, the system displays the results as color maps.

Assumptions:

The monitoring event for the specific date and temperature range exists.

The identity of the data-monitoring event is not null.

Calculate and Display Heat Flux

This use case allows the user to get values of heat flux on the five faces of the box and display in 2-D or 3-D format using contours or color maps.

The user selects one data set from the search results displayed.

Given the above selection, the system displays the results as heat flux calculation.

Assumptions:

The monitoring event for the specific date and temperature range exists.

The identity of the data-monitoring event is not null.

5.3.3. Administration Use Cases

This function allows the user to edit, update or delete records from the tables that exist in the database.

Display Data

This use case lets the user view the data for all the data events existing in the database.

The system retrieves data from the database and displays all the data events and the temperature of the sensors for that event.

Edit and Add Data

This use case allows the user to edit the data for the data events existing in the database or add new events into the database.

- The user makes a change to or adds to the data
- The user submits information
- The system identifies if whether that data event exists in the database
- If yes, the system updates the data with that corresponding data event
- If not, the system creates a new data event and adds the new record to the database.

Assumptions:

Only staff user is given the administrative privilege

In event of the failure to record data directly from the sensors or error in the data received from the sensors this use case would be mainly used.

6. Web Interface Design

6.1. .NET Framework

As part of the new .NET Framework, MS provides a new programming language, C#, and several classes to manage web controls on server-side, code-behind files as part of ASP.NET. In addition, the framework provides more options for state management than traditional ASP.

6.1.1. Server-side scripting

ASP.NET employs server compiled and processed scripts that can be removed from HTML documents and placed in code-behind files. This allows for the code that drives HTML and web control components to be divorced in a way that limits programmer confusion.

6.1.2. Managing state

More importantly, the .NET framework provides several options for managing state, which is important in site navigation of a database-driven web application. More specific to the HVRL system, the initial search produces a dataset with complete relational structure that has been analyzed in further activity steps. In ASP.NET, state can be managed both server-side and client-side with expected gains and losses in performance occurring with each option.

In addition to traditional query string (i.e. http://www.somedomain.com/MyProject.aspx?value=3&sensors=10), or cookies, ASP.NET provides classes for both server and client side storage of large datasets, which can survive page restarts in a web application. Choice had to be made in this regard i.e. whether to utilize these classes and either pass complete data readers or datasets between pages or whether greater performance would be achieved by simply passing the search query and re-executing the query. The design of the interface, along with experimentation during software development governed these decisions.

6.1.3. Microsoft Visual Studio .NET Integrated Development Environment

The VS.NET IDE affords a great deal of flexibility in generating GUI's with code-behind classes in the .NET framework. The .NET Framework includes a number of classes that can be used to provide an application driven by a GUI. The web application for this project has been developed with this tool. Although it is possible to produce the program using any text editor, the IDE Visual Studio.NET has a wizard that can be used to generate a Windows Forms application. If this is used, one can generate the program by dragging a TextBox, a Button and a Label from the toolbox onto a form and then adding the C# code to respond to a click of the button. The appropriate wizard can be used to produce (in a file called MyWebForm.aspx) a WWW page containing the form. Note that the HTML instructions (for the WWW page) and the C# code are in separate files. This separation means that the two files could be looked after by different people. The WWW page can be visited using a URL, which is something like:

http://machine.site.ac.uk/WebFormConvert/MyWebForm.aspx

This is an ASP.NET page, and so machine.site.ac.uk would need to be running Microsoft's Internet Information Server (IIS) as a web server.

6.1.3.1. Software Design Model

The software design model followed is structured loosely here under a Model – View – Controller hierarchy.

Model: Data Handling Procedures and Classes

Functions that implement queries based on input options and return data rendering objects. These methods and classes are not deeply dependent on the final user interface, and have been coded and tested independently, given the current data model.

View: Continued GUI Construction

This includes the web pages that have been constructed with navigation implemented. Furthermore, the layout and style schemes have been updated. Cascading Style Sheets have been employed. Whenever possible, care has been taken to use a traditional HTML component where one would suffice. However, because of the project is a web application, many of the GUI components are web controls (ActiveX), each representing the consumption of some system resources.

Controller: State Management Decisions

Decisions for how data will be passed and maintained through paged have been made with both the GUI and Data procedures kept in mind.

6.1.3.2. Project and Classes

ProceduralSQLQuery: This is a main web application that is used to provide the user interface for the data analysis. The database made in SQL Server 2000 renders the data to be published to the web form. We use user.xml to provide authentication. The ThermalAnalysis.aspx, TempReadings.aspx, and TempRange.aspx files contain all the queries that are made to the database. One query is to find the monitoring-event at a given time, the other to find all the temperature values corresponding to a particular event, and the third is to display temperature values within a user-specified range for a given time. The SQL queries are done by means of stored procedures.

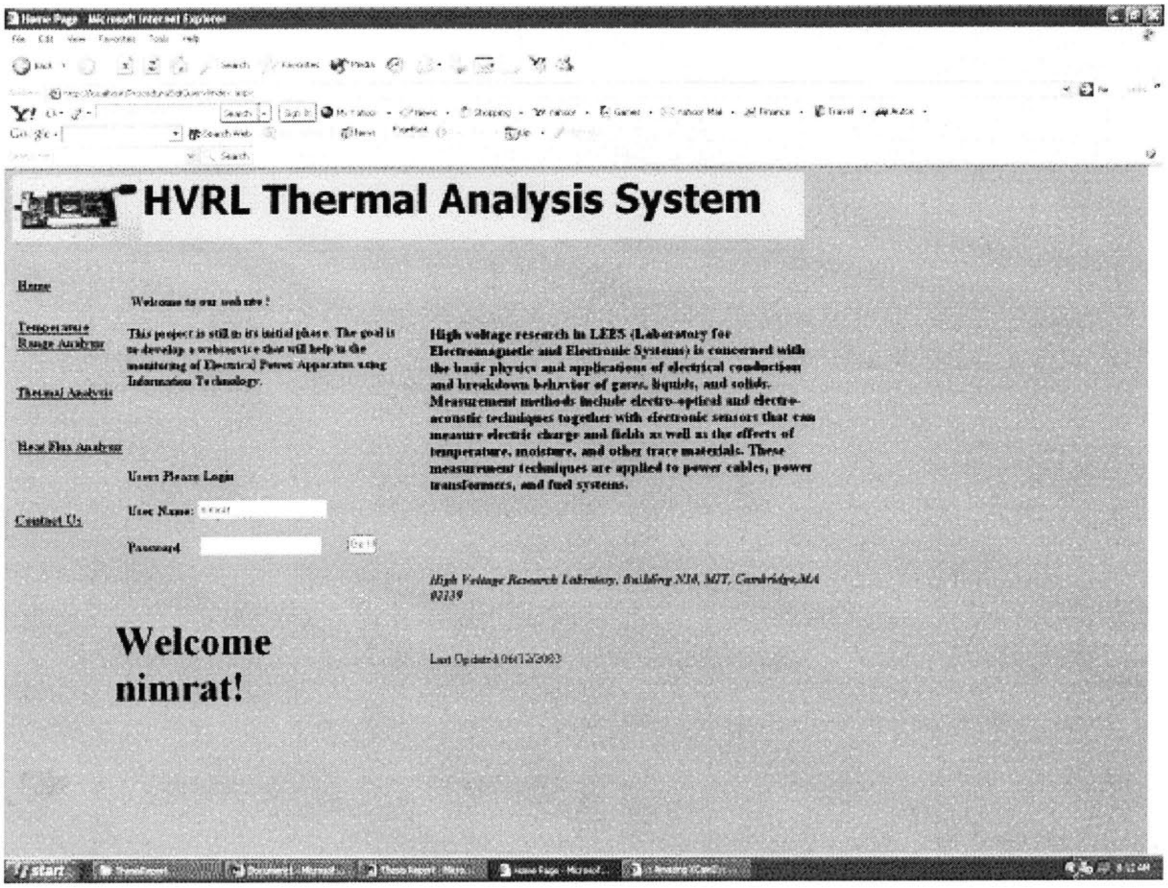
The file BarChartUI.aspx, plots a bar chart of all the temperature values corresponding to a particular event. PoinUI.aspx, as shown in Fig.25 and Fig. 26 of Appendix I, displays color-coded temperature values for all the sensors at different points on the cube in 2-D. The Contour.aspx, as shown in Fig.27 of Appendix I, displays the contours on 2D grid after taking data from the database corresponding to a particular event ID.

6.2. Web Pages Design

At this point four main page views have been designed, each of which encompasses a major piece of functionality as outlined in the UML Activity Diagram.

6.2.1. Home Page and Login

For security reasons, we provide user authentication before allowing the user to access the data. Fig 15 is a snapshot of the home page and it asks for authorized users to login.


Home Page - Microsoft Internet Explorer
Home
Temperature Range Analyzer
Thermal Analysis
Heat Flux Analyzer
Contact Us
Go !!

HVRL Thermal Analysis System

Welcome to our web site !

This project is still in it's initial phase. The goal is to develop a webservice that will help in the monitoring of Electrical Power Apparatus using Information Technology.

High voltage research in LEES (Laboratory for Electromagnetic and Electronic Systems) is concerned with the basic physics and applications of electrical conduction and breakdown behavior of gases, liquids, and solids. Measurement methods include electro-optical and electro-acoustic techniques together with electronic sensors that can measure electric charge and fields as well as the effects of temperature, moisture, and other trace materials. These measurement techniques are applied to power cables, power transformers, and fuel systems.

Users Please Login

User Name: nimrat

Password

High Voltage Research Laboratory, Building N10, MIT, Cambridge,MA 02139

Welcome nimrat!

Last Updated 06/12/2003

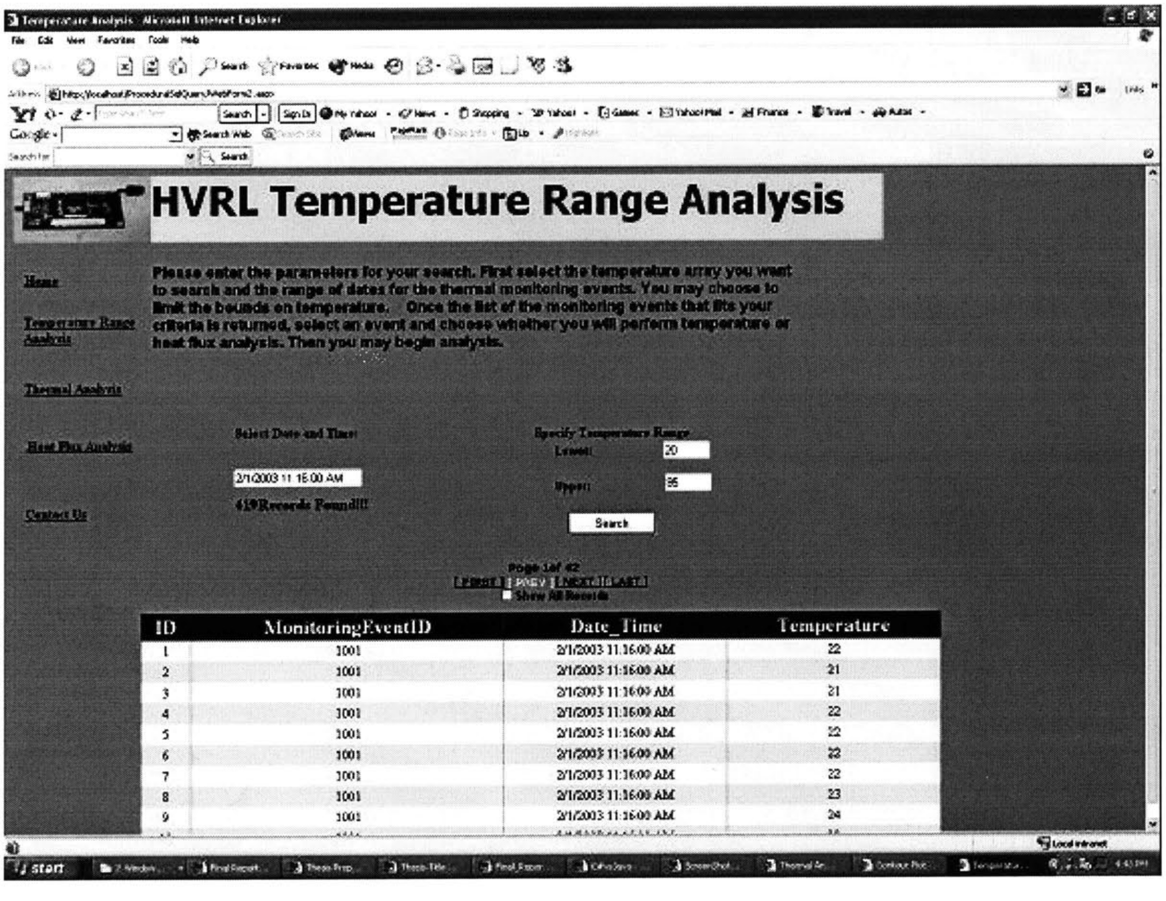
Figure 15: Login and Home Page

When the user enters the username and password in the corresponding fields on the website, the system checks for permissions. An authorized user can see a menu bar on the left side, which contains links to various parts of the web site.

The login is relatively straightforward. Windows forms authentication against an xml file is provided. If the login fails to authenticate, the "Please login:" label can be changed upon post-back. If the login authenticates, the user will be returned to the search page and a hidden login label will become visible that will inform the user he has logged in successfully. All of this has been be supplemented with Windows Authentication.

6.2.2.Temperature Range Search Page

The temperature analysis is done by a query feature that provides for finding out the temperature readings within a particular user specified value range for a particular date. It asks users to choose the minimum and the maximum values over which temperature values are required. Once the user enters the value, the stored SQL procedure finds out all the values in that range from the database and displays them in a datagrid as shown in Fig 16. The datagrid takes maximum 10 rows of results per page, therefore smart navigation has been provided using buttons to navigate through various pages. If the user wants to see all the records on same page, this can be done by checking the "Show All Records" checkbox. The page also displays the total number of records found.


Home
Temperature Range Analysis
Thermal Analysis
Heat Flux Analysis
Contact Us
Search
[FIRST] [PREV] [NEXT] [LAST]

HVRL Temperature Range Analysis

Please enter the parameters for your search. First select the temperature array you want to search and the range of dates for the thermal monitoring events. You may choose to limit the bounds on temperature. Once the list of the monitoring events that fits your criteria is returned, select an event and choose whether you will perform temperature or heat flux analysis. Then you may begin analysis.

Select Date and Time: 2/1/2003 11:16:00 AM

419Records Found!!!

Specify Temperature Range
Lower: 20
Upper: 35

Page 1of 42

□ Show All Records

ID	MonitoringEventID	Date_Time	Temperature
1	1001	2/1/2003 11:16:00 AM	22
2	1001	2/1/2003 11:16:00 AM	21
3	1001	2/1/2003 11:16:00 AM	21
4	1001	2/1/2003 11:16:00 AM	22
5	1001	2/1/2003 11:16:00 AM	22
6	1001	2/1/2003 11:16:00 AM	23
7	1001	2/1/2003 11:16:00 AM	22
8	1001	2/1/2003 11:16:00 AM	23
9	1001	2/1/2003 11:16:00 AM	24

Figure 16: Temperature Range Search Page

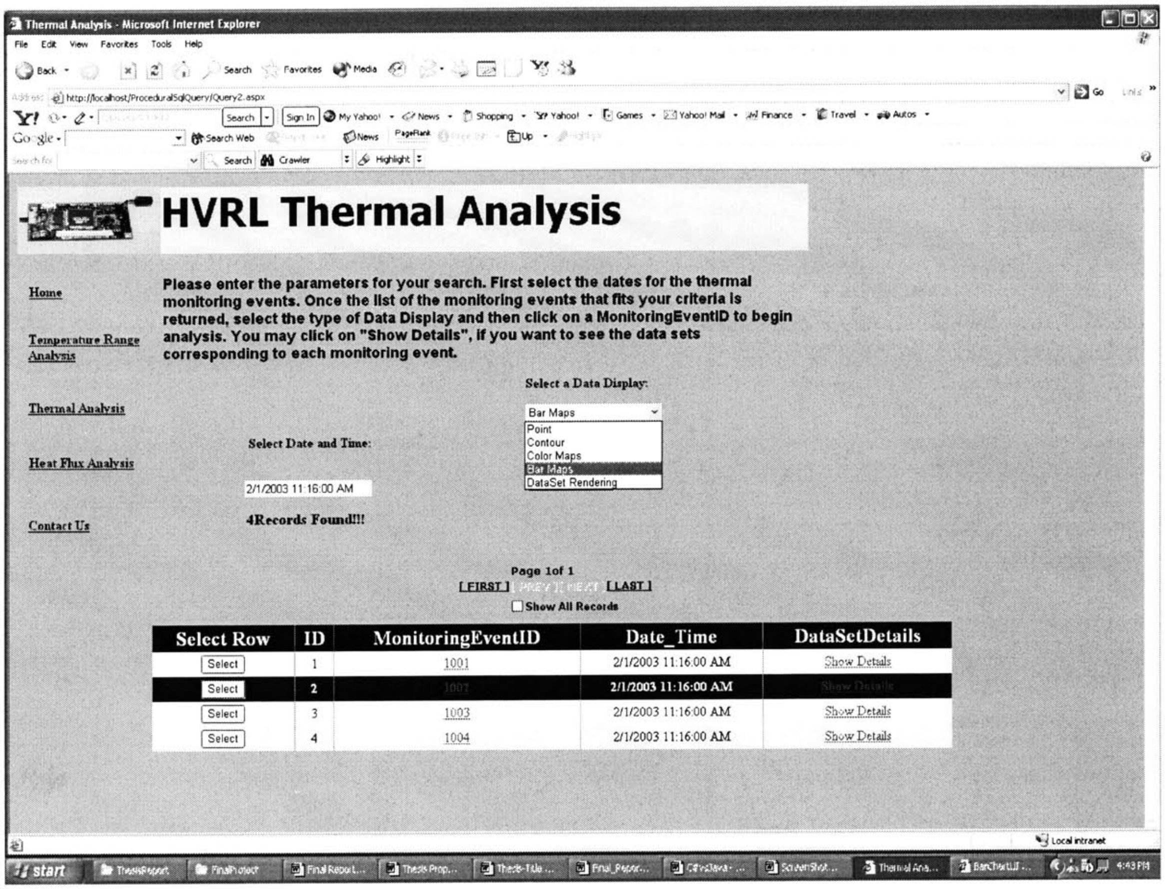
6.2.3. Data Analysis

Data analysis has been managed by two pages: Thermal Analysis and Heat Flux Analysis. The interface is similar enough that the page can remain constant as the components updates. By caching the data object (in whatever class/object representation chosen) between posts to the server (with either server-side or client-side caching), an increase in performance and efficiency may be realized. Specific to the page, basic information about the data is displayed. This label configured to show specific descriptions about the data set being analyzed. In addition, all the previously searched monitoring events are available to process here, rather than having to go back and retype a search. Presently, the change analysis radio box shows only one option. In the future, multiple forms of analysis may be available.

6.2.3.1.Thermal Analysis Page

The Thermal Analysis page shown in Fig. 17 below outlines the major functionality of the website. It provides options for searching as outlined and revised in earlier designs of functional requirements. The screen shots below represent working software components with identification in a C# code – behind file.

The user interface provides for users to query the database that contains readings of temperature data. Users can look at the temperature value at a particular instant in the past. The users need to submit the date (format: month/day/year Hr:Min:Sec e.g. 30/12/2003 11:56:34 PM). This needn't be a complete time, for e.g. 11:56 will return all the readings starting with 11:56). The application returns the results based on a stored SQL Query (stored procedure) running over a SQL server database. The corresponding data is displayed in a datagrid. The datagrid takes maximum 10 rows of results per page, therefore smart navigation has been provided using buttons to navigate through various pages. If the user wants to see all the records on same page, this can be done by checking the "Show All Records" checkbox. The page also displays the total number of records found.


Thermal Analysis - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
http://localhost/ProceduralSqlQuery/Query2.aspx
Go
Search Sign In My Yahoo! News Shopping Yahoo! Games Yahoo! Mail Finance Travel Autos
Google Search Web News PageRank Up
Search Crawler Highlight
Home
Temperature Range Analysis
Thermal Analysis
Heat Flux Analysis
Contact Us
Point
Contour
Color Maps
Bar Maps
DataSet Rendering
[FIRST] [PREV] [NEXT] [LAST]
Local intranet
start ThesisReport FinalProject Final Report... Thesis Prop... Thesis-Title... Final_Paper... ScreenShot... Thermal Ana... BarChartUI... 4:43 PM

HVRL Thermal Analysis

Please enter the parameters for your search. First select the dates for the thermal monitoring events. Once the list of the monitoring events that fits your criteria is returned, select the type of Data Display and then click on a MonitoringEventID to begin analysis. You may click on "Show Details", if you want to see the data sets corresponding to each monitoring event.

Select a Data Display: Bar Maps

Select Date and Time: 2/1/2003 11:16:00 AM

4Records Found!!!

Page 1of 1

□ Show All Records

Select Row	ID	MonitoringEventID	Date_Time	DataSetDetails
Select	1	1001	2/1/2003 11:16:00 AM	Show Details
Select	2	1002	2/1/2003 11:16:00 AM	Show Details
Select	3	1003	2/1/2003 11:16:00 AM	Show Details
Select	4	1004	2/1/2003 11:16:00 AM	Show Details

Figure 17: Thermal Analysis Search Page Display

The thermal analysis page is designed to be controlled so that the Monitoring Event list and the analysis type i.e. the data display selection will only become visible once an initial data set is rendered by pressing the “search” button. The drop-down list contains the different display options available. Once the user selects the display type and clicks on the “MonitoringEventID” the display for that particular event ID is done. The “ Show Details” button gives the temperature data for the 105 sensors corresponding to a particular monitoring-event as shown in Fig.24 of Appendix 1. If login session for a particular user expires or the user is not logged-on the user is taken back to the home page and asked to login.

The Thermal Analysis page also includes the following display options:

Dynamic Thermal Bar and Point Charts: A dynamically generated web charts have been plotted where users could choose a particular event for a valid time on a particular day. Then the user is able to visualize the thermal data in that time through a bar or a

`

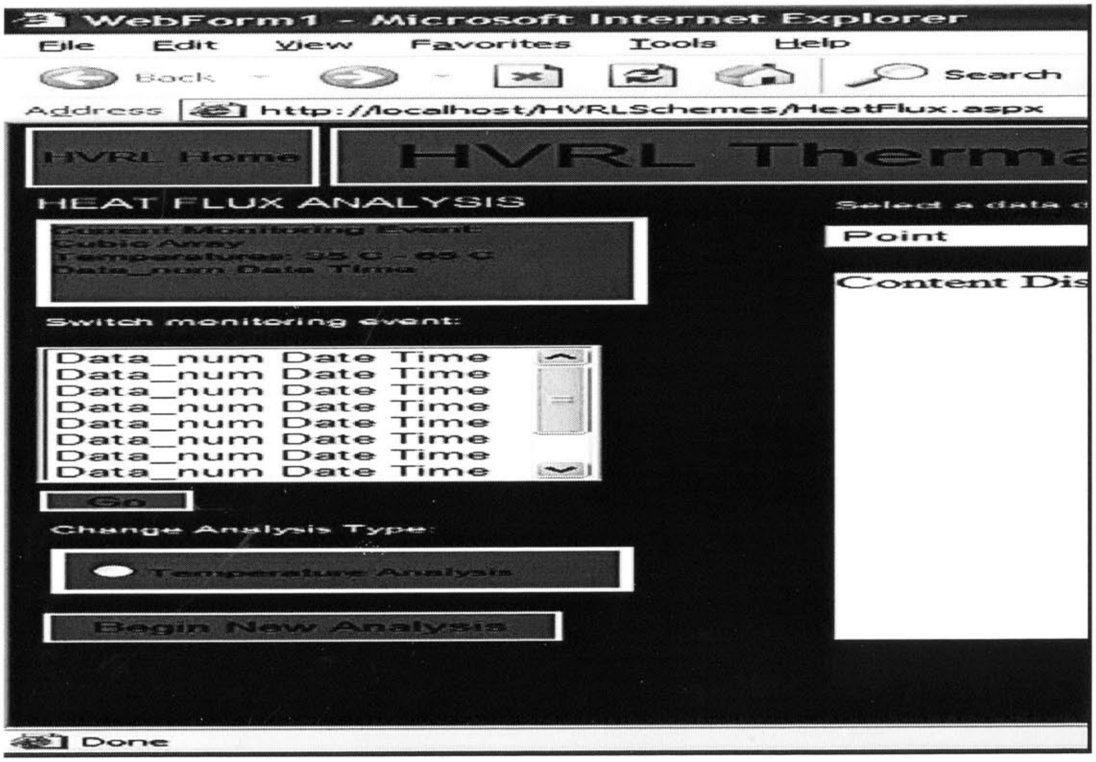
point chart. I have used the GDI+ classes of the .NET library for plotting the bar charts. When the user clicks on any particular monitoring event ID, the temperature for all the 105 sensors corresponding to that particular event are plotted in the bar or point chart format as shown in Fig. 25 and Fig. 26 of Appendix 1.

DataSet Rendering: This is same as the "Show Details" feature, which displays temperature data for all the 105 sensors corresponding to a particular event ID.

Contour Maps: Current open source algorithms has been modified for C# and ASP.NET for discrete contours. Java Applet, which generates contours by taking data from the database for the selected monitoring event ID has been imbedded in a web form, is shown in Fig. 27 of Appendix 1. In addition, for smooth contours (color maps) of the thermal arrays, can also be generated but it has not been implemented for this project.

6.2.3.2. Heat Flux Analysis

The heat flux analysis specific interface is shown in greater in Fig.18. However, this was not implemented in the current project due to limitations of time and resources.



Address http://localhost/HVRLSchemes/HeatFlux.aspx

HVRL Home

HVRL Therm

HEAT FLUX ANALYSIS

Current Monitoring Event:
Cubic Array
Temperatures: 35 C - 65 C
Data_num Date Time

Switch monitoring event:

Data_num Date Time
Data_num Date Time
Data_num Date Time
Data_num Date Time
Data_num Date Time
Data_num Date Time
Data_num Date Time
Data_num Date Time

Go

Change Analysis Type:

● Temperature Analysis

Begin New Analysis

Select a data d

Point

Content Dis

Figure 18: Heat Flux Analysis

7. Product Development Process

7.1. Team Model.

Our team model is based on Microsoft Framework, which assigns basic 6 roles for each team. MSF model's roles are like these: Product Management, Program management, Development, Testing, User Education, and Logistics Management. The tasks that should be done by each role are indicated in Table 3 below. The business model for the project would also be based on this team model.

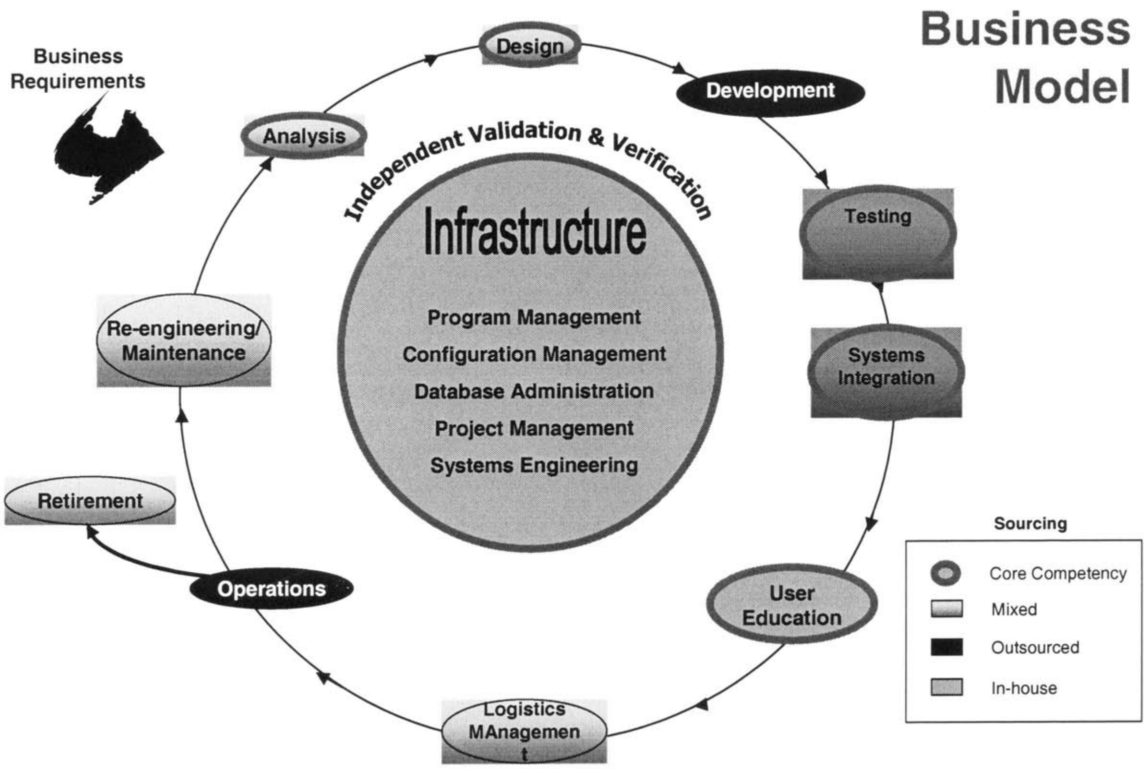


Figure 19: Team Business Model for the HVRL Thermal Analysis System

Role	Mission
Project Management	Acts as customer advocate to the team Acts as team advocate to the customer Drives shared project vision Manages customer expectations Develops, maintains, and executes the business case Drives feature identification and prioritization Develops, maintains, and executes the communications plan
Program Management	Drives the overall process Manages resource allocation Manages the project schedule and reports project status Manages the product scope and specification Facilitates team communication and negotiation Drives overall critical trade-off decisions
Development	Builds and tests features to meet the specification and customer expectations Participates in design Estimates time and effort to complete each feature Serves the team as a technology consultant
Testing	Develops testing strategy, plans, and scripts Manages the build process Conducts tests to accurately determine the status of product development Participates in setting the quality bar
User Education	Acts as team advocate to the end user Acts as end-user advocate to the team Participates in defining user requirements Participates in designing features Designs and develops user support systems Drives the usability process
Logistics Management	Acts as team advocate to operations Acts as operations advocate to the team Plans and manages product deployment Participates in design, focusing on manageability, supportability, and deployability Supports the product during beta testing Trains operations and help desk personnel for product release

Table 3: Team Model

However, the project team is composed of only 2 members one of whom left midway during the project, and Dr. George Kocur played 'Program Management' role. Therefore, three of us used modified version of MSF that is scaled down for small teams.

7. 2. Product Development Process

We adopted Milestone-Driven Process as our product development process. In this process, we set several milestones that are review and synchronization points, not freeze points. There are two kinds of milestones, major milestones and interim milestones. Achieving a major milestone represents team and customer agreement to proceed, and team can prove that they reached a milestone by delivering the product.

In the whole project, what I needed to do was developing means to search and analyze data stored in the database from the sensors. Other researchers had done other parts, like installing the sensors or programming the sensors. The other thing I considered is policy and business perspective for the project. Actually, those two parts can present a blueprint only based on the real network product, so I set milestones for both the parts almost at the end of the process.

The Product Development Process was divided into 5 phases described below:

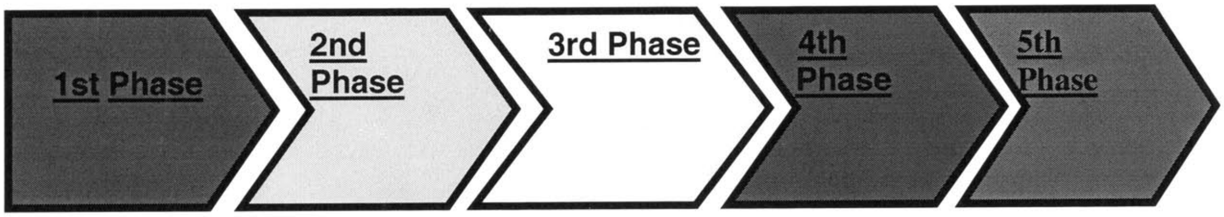


Figure 20: Product Development Process

- **First Phase (Month 1):**
  1. Requirements
  2. Database Design
  3. Features development.
- **Second Phase (Month 2):**
  1. Coding and Testing

2. Internal Release 1 & Milestone Review.

- **Third Phase (Month 3):**
  1. Feature Development.
  2. Testing &Stabilizing.
- **Fourth Phase (Month 4):**
  1. Internal Release 2 &Milestone Review.
- **Fifth Phase (Month 5):**
  1. Buffer Time, Business survey & Political Review.
  2. Real Release, Business and Policy Analysis
  3. Conclusion.

7.3. Trade-offs Discussion

Managing a project requires balancing the factors of resource, project scope, and schedule. If one of these factors is changed, it will affect the other two. Each factor is identified as to the ability for it to be modified. For this specific project, the state is shown in Table 4 below:

Resource	**Project Scope**	**Schedule**
Semi-Flexible	Flexible	Fixed

Table 4: Factors affecting the project

Fixed: Constrained meaning the factor cannot be changed.

Semi-Fixed: Accepted meaning the factor is somewhat flexible to the project circumstances.

Flexible: Improved meaning the factor can be adjusted.

Initially, our team was composed of two members, but in the middle of the semester, one of the team members dropped the project. Therefore, the project lost 50% of human resource. However, we could not change schedule because the project had a pre-assigned deadline. So, many features had to be dropped from the project.

8. Current Problems:

Some of the problems we currently face with the system, which can act as deterrent for companies to invest in this area, are:

- **Data monitoring is not really real time**

Half Duplex: it's impossible to receive signals while transmitting

Motes get too busy as they get to the base station

- **Analyzing the data & Making the standard**

We still need to put in place a system, which can decide critical thermal patterns for the transformer based on the temperature data. Currently, we only have the data coming in from the sensors but no means to compare it against a standard so as to deduce what a particular temperature value means.

- **Developing Market**

We would have to compete with the traditional monitoring & maintaining methods, which are well established and tested.

Developing different version of wireless sensor monitoring system depending upon the requirements would make more sense than having a single uniform version.

- **Contour Plotting and Color Maps**

The contour plotting and smoothing of curves is a very tedious process. Time restrictions did not give me enough opportunity to go into details for developing an algorithm for color maps. Once alternative is to buy currently available contour plotting software off the shelf and customize it according to our requirements.

9. Future Work

The real-time monitoring can be expanded to include these possible criteria for targeting other potential customers. New entrant or substitutes can be possible in these directions:

- Development of customizable GUI for easy access to critical measurement statistics.

- Calculating Heat Flow though the cube box assuming steady state as well as for time variations.
- 3-D representations for the color-encoded temperatures as well as "morphing" temperature changes over time live using a web service. Images over the web can be sent every few seconds after plotting of the real time data.
- Development of advanced alarm notification techniques (i.e. pager and mobile phone contact for alarm situations ensuring proper action).
- Customizing the web-user interface for smart devices like PDAs, which can be easily carried in-person by workers.
- Expansion of services into other safety areas such as monitors for oil levels, noise levels, waveform analysis and other safety concerns.
- Developing a web service for publishing real time data over the web. Even .NET Remoting or direct socket connection can be used while allowing multiple clients to connect to the web server for the data access (using multi threading). The latter would deliver more accurate real time data to the clients.
- Trigger Web Services: As a part of future work, one can write web applications, which get triggered when the temperature shoots above a certain value. Thus, we can have trigger web services based on real time sensor data.
- Data Archiving: Data archiving is a big issue in real time data storing. One can write an application that creates Zip files of old data (which can be accessed if queried upon).

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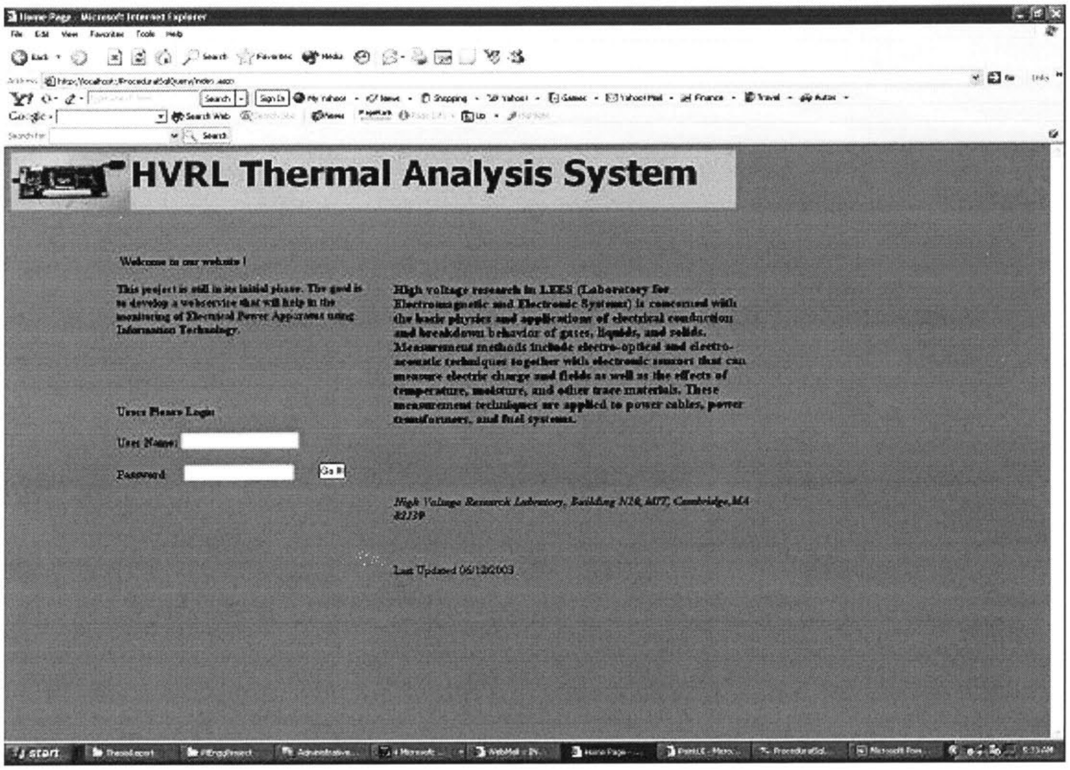
APPENDIX 1: SCREEN SHOTS OF WEB USER INTERFACE PAGES


Home Page - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Go Links
start

HVRL Thermal Analysis System

Welcome to our website !

This project is still in its initial phase. The goal is to develop a webservice that will help in the monitoring of Electrical Power Apparatus using Information Technology.

Users Please Login

User Name:

Password:

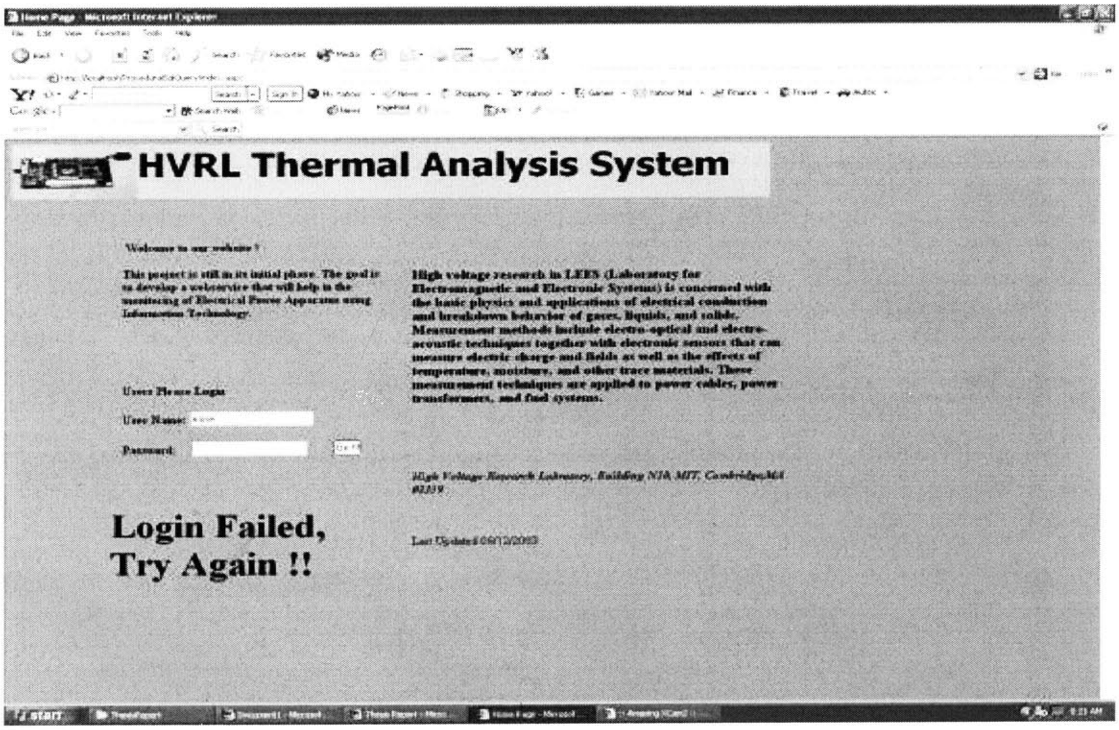
Go !!

High voltage research in LEES (Laboratory for Electromagnetic and Electronic Systems) is concerned with the basic physics and applications of electrical conduction and breakdown behavior of gases, liquids, and solids. Measurement methods include electro-optical and electro-acoustic techniques together with electronic sensors that can measure electric charge and fields as well as the effects of temperature, moisture, and other trace materials. These measurement techniques are applied to power cables, power transformers, and fuel systems.

High Voltage Research Laboratory, Building N10, MIT, Cambridge,MA 02139

Last Updated 06/12/2003

Figure 21: Home Page


Home Page - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
start

HVRL Thermal Analysis System

Welcome to our website !

This project is still in its initial phase. The goal is to develop a webservice that will help in the monitoring of Electrical Power Apparatus using Information Technology.

Users Please Login

User Name:

Password:

Go !!

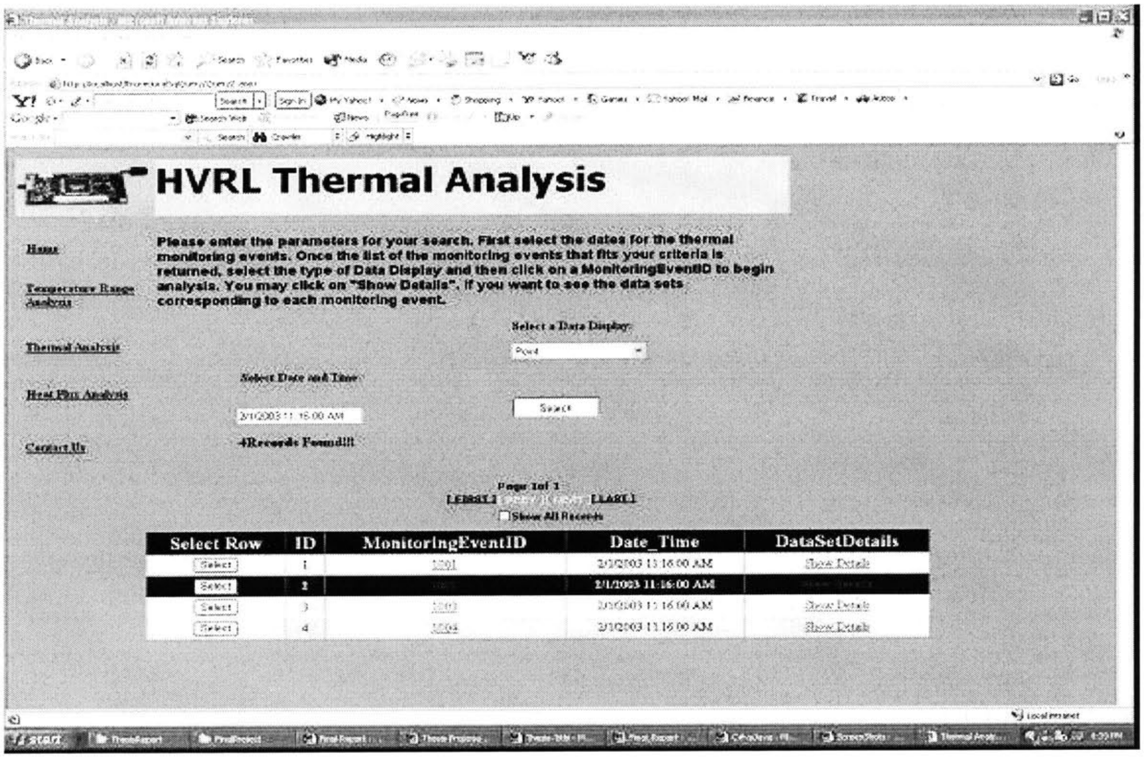
Login Failed,
Try Again !!

High voltage research in LEES (Laboratory for Electromagnetic and Electronic Systems) is concerned with the basic physics and applications of electrical conduction and breakdown behavior of gases, liquids, and solids. Measurement methods include electro-optical and electro-acoustic techniques together with electronic sensors that can measure electric charge and fields as well as the effects of temperature, moisture, and other trace materials. These measurement techniques are applied to power cables, power transformers, and fuel systems.

High Voltage Research Laboratory, Building N10, MIT, Cambridge,MA 02139

Last Updated 06/12/2003

Figure 22: Login Page when login failed



HVRL Thermal Analysis

Please enter the parameters for your search. First select the dates for the thermal monitoring events. Once the list of the monitoring events that fits your criteria is returned, select the type of Data Display and then click on a MonitoringEventID to begin analysis. You may click on "Show Details", if you want to see the data sets corresponding to each monitoring event.

Select a Data Display: Point

Select Date and Time: 2/1/2003 11:16:00 AM

Search

4Records Found!!!

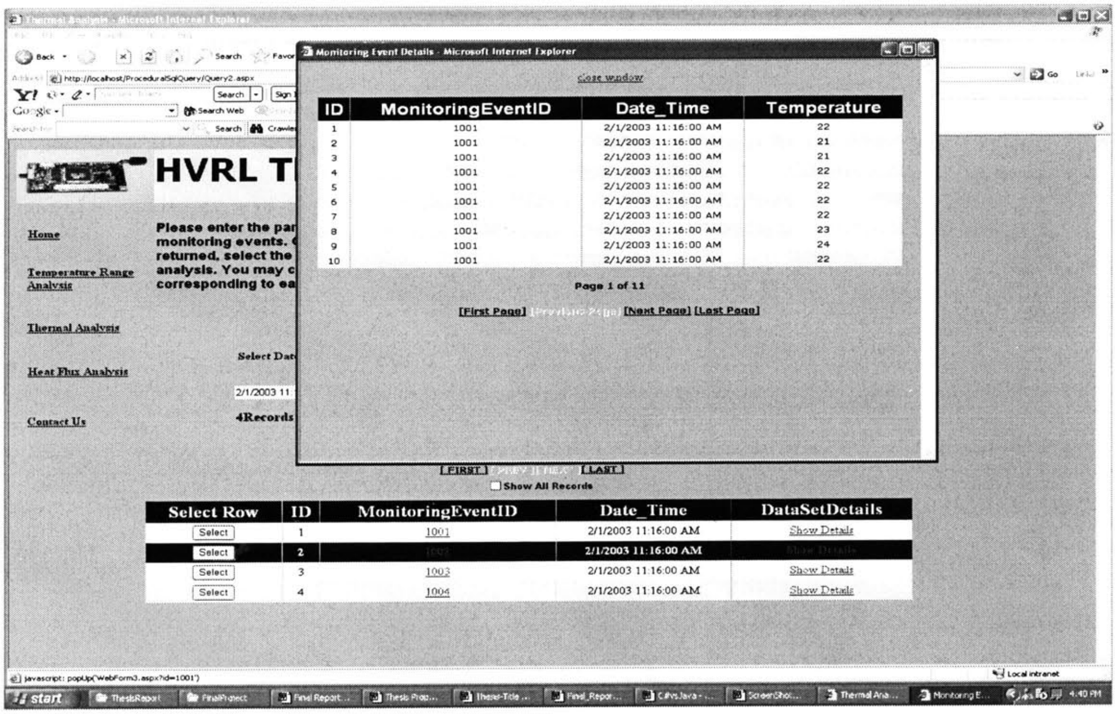
Page 1of 1

[FIRST] [PREV] [NEXT] [LAST]

□ Show All Records

Select Row	ID	MonitoringEventID	Date_Time	DataSetDetails
Select	1	1001	2/1/2003 11:16:00 AM	Show Details
Select	2	1002	2/1/2003 11:16:00 AM	Show Details
Select	3	1003	2/1/2003 11:16:00 AM	Show Details
Select	4	1004	2/1/2003 11:16:00 AM	Show Details

Figure 23: Thermal Analysis Search Page



Monitoring Event Details - Microsoft Internet Explorer

Close window

ID	MonitoringEventID	Date_Time	Temperature
1	1001	2/1/2003 11:16:00 AM	22
2	1001	2/1/2003 11:16:00 AM	21
3	1001	2/1/2003 11:16:00 AM	21
4	1001	2/1/2003 11:16:00 AM	22
5	1001	2/1/2003 11:16:00 AM	22
6	1001	2/1/2003 11:16:00 AM	22
7	1001	2/1/2003 11:16:00 AM	22
8	1001	2/1/2003 11:16:00 AM	23
9	1001	2/1/2003 11:16:00 AM	24
10	1001	2/1/2003 11:16:00 AM	22

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[First Page] [Previous Page] [Next Page] [Last Page]

[FIRST] [PREV] [NEXT] [LAST]

□ Show All Records

Select Row	ID	MonitoringEventID	Date_Time	DataSetDetails
Select	1	1001	2/1/2003 11:16:00 AM	Show Details
Select	2	1002	2/1/2003 11:16:00 AM	Show Details
Select	3	1003	2/1/2003 11:16:00 AM	Show Details
Select	4	1004	2/1/2003 11:16:00 AM	Show Details

javascript: popUp('WebForm3.aspx?id=1001')

Figure 24: DataSet Details Corresponding to Monitoring Event ID

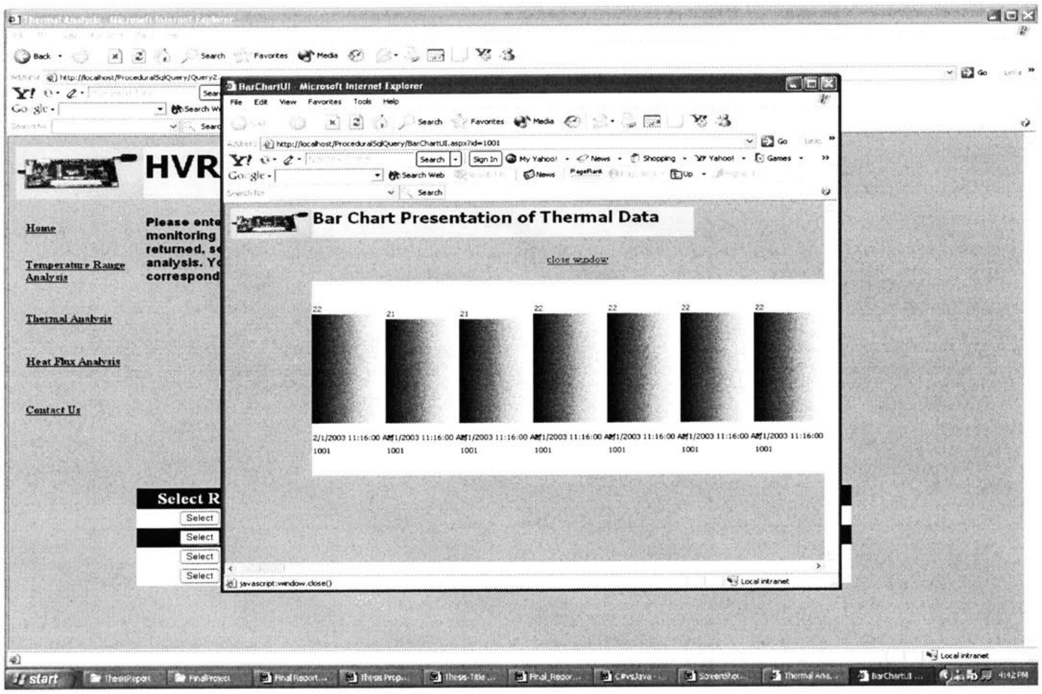


Figure 25: Dynamic Bar Chart

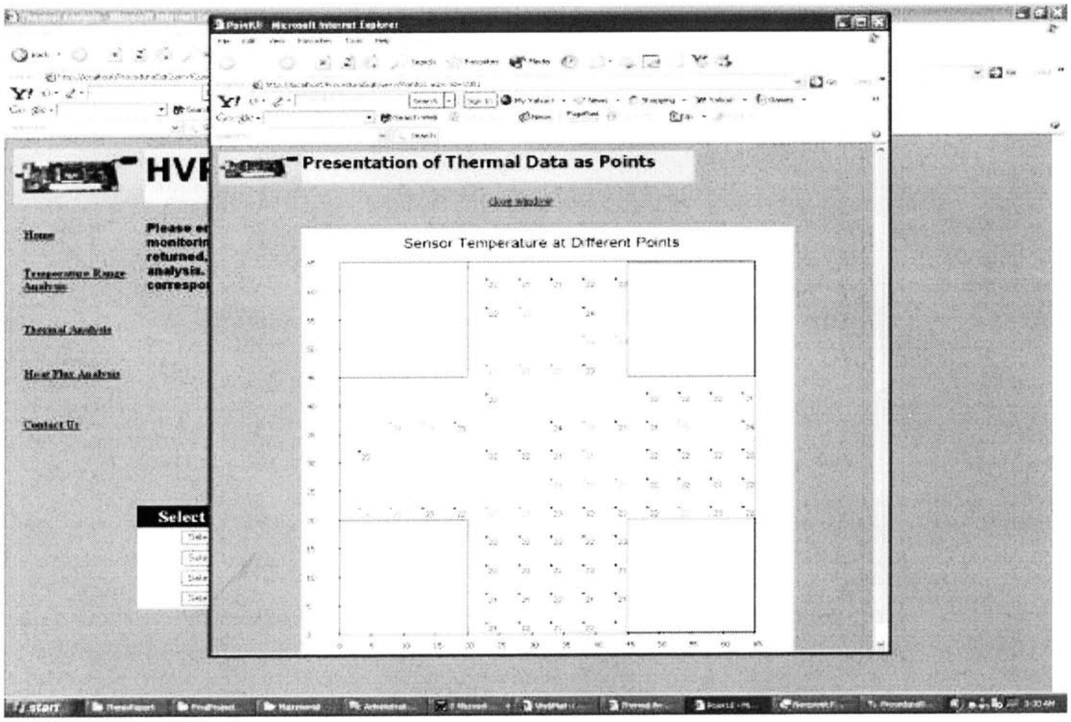
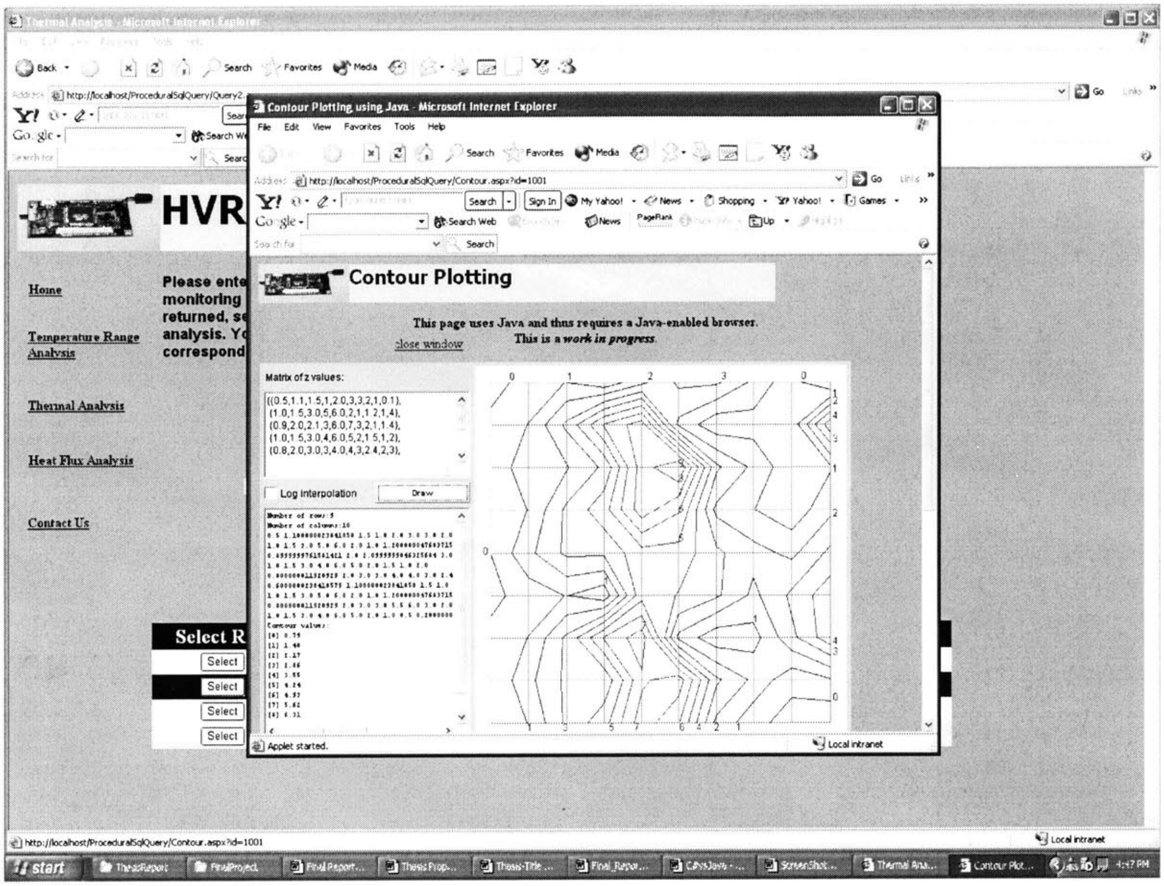


Figure 26: Dynamic Point Chart


Thermal Analysis - Microsoft Internet Explorer
Contour Plotting using Java - Microsoft Internet Explorer
File Edit View Favorites Tools Help
http://localhost/ProceduralSqlQuery/Contour.aspx?id=1001
HVR
Home
Temperature Range Analysis
Thermal Analysis
Heat Flux Analysis
Contact Us
Please ente
monitoring
returned, se
analysis. Yo
correspond
Select R
Select
Select
Select
Select
close window
Log interpolation
Draw
Applet started.
Local intranet
start

Contour Plotting

This page uses Java and thus requires a Java-enabled browser.
This is a *work in progress*.

Matrix of z values:

```
{{0.5,1.1,1.5,1,2.0,3,3,2,1,0.1},
 {1.0,1.5,3.0,5,6.0,2,1,1.2,1,4},
 {0.9,2.0,2.1,3,6.0,7,3,2,1,1.4},
 {1.0,1.5,3.0,4,6.0,5,2,1.5,1,2},
 {0.8,2.0,3.0,3,4.0,4,3,2.4,2,3},
```

```
Number of rows:5
Number of columns:10
0.5 1.100000023841858 1.5 1.0 2.0 3.0 3.0 2.0
1.0 1.5 3.0 5.0 6.0 2.0 1.0 1.2000000476837715
0.8999999761581421 2.0 2.0999999046325684 3.0
1.0 1.5 3.0 4.0 6.0 5.0 2.0 1.5 1.0 2.0
0.800000011920929 2.0 3.0 3.0 4.0 4.0 3.0 2.4
0.6000000238418579 1.100000023841858 1.5 1.0
1.0 1.5 3.0 5.0 6.0 2.0 1.0 1.2000000476837715
0.800000011920929 2.0 3.0 3.0 5.5 6.0 3.0 2.0
1.0 1.5 3.0 4.0 6.0 5.0 2.0 1.0 0.5 0.2000000
Contour values:
[0] 0.79
[1] 1.48
[2] 2.17
[3] 2.86
[4] 3.55
[5] 4.24
[6] 4.93
[7] 5.62
[8] 6.31
```

Figure 27: Contour Maps