SCIENTIFIC VISUALIZATION OF BIOHEAT PROCESS

ROSNANI RAMIN
WEK020218

FACULTY OF COMPUTER SCIENCE
AND
INFORMATION TECHNOLOGY

UNIVERSITY OF MALAYA

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ABSTRACT

Development in visualization technology is changing the way science is undertaken in many areas of research. This project is a system specifically designed to manage and visualize the temperature data of the human body.

Knowledge in certain domains is very important in developing the visualization of bioheat process system. There are two main areas of research needed to carry out in order to marks the whole project succeed, research on the visualization program tools and research on the bioheat process in the human body. As the result of research, MATLAB was chosen to be the core-programming tool.

An important aspect of this system is to visualize temperature bioheat processes of heat transfer. The objective of this system is to illustrate how programming, modeling and simulation of a transient PDE problem using a mathematical software package in MATLAB.

There are two major categories of user had been determined, which can be categorized into expert and non-expert user. The user will benefit from this system as it is visualization and it is repository that is rich in various artificial intelligent and multimedia contents.

ACKNOWLEDGEMENT

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Introduction

CHAPTER 1: INTRODUCTION

1.1 Project Overview

This report proposed the development of a system, which is can gain knowledge about visualization of human body temperature and will include many different categories of users. This project includes the theoretical modeling of high and low temperature heat with particular emphasis on phase change phenomena.

The project it also is equipped with easy to understand instructions and very user-friendly interface, which will attract both computer literate. User can better visualize the temperature behaviors, and explore the effect of changes in system geometry, and properties.

Furthermore, this system tries to illustrate the linkage between theoretical concepts of multidimensional transient heat conduction and computer simulation using MATLAB. The resulting parabolic partial differential equation (PDE) is solved using finite difference method and PDE Toolbox (pdetool). This system considers successively linear system corresponding to the bioheat transfer problem corresponding to a Pennes' model.

1.2 Objectives of project

The main objective is to develop a system which suitable numerical methods for visualization of bioheat process. The visualization of bioheat process hopes to realize the following objectives:

1. Theoretical modeling of heat transfers process involves problem solving.
2. Visualizing of temperature in human body with cognitive science principle.
3. To study heat processes - bioheat process in skin burn and hyperthermia (cancer therapy).
4. To visualize in different ways the temperature values in analyzing the process by various experts

1.3 Scope of project

The scope of this project is based on the project objectives. This system can use by expert user (cancer specialist) to visualization of temperature distributions on a very complicated geometry and non-expert user (patient) to get information in human body temperature. It has two category user can use this system:

- Expert user – use the system to know the temperature and to determine the temperature using visualization with arrow, height 3D and contour.
  - active decision making to give the treatment based on the temperature visualization.
- Non-expert – use to determine the temperature using visualization with colour.
  - passive decision making which is just get information using visualization.

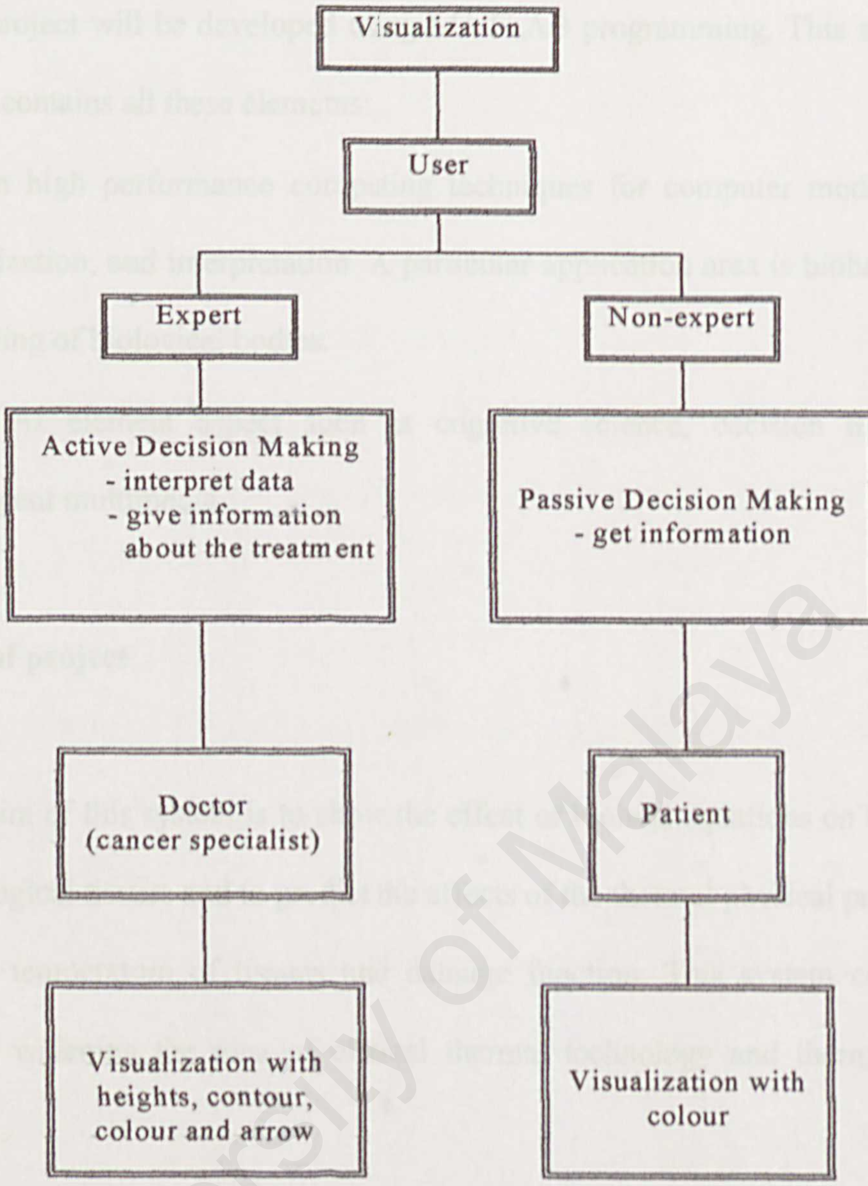


Figure 1: Scope of the project

This project will be developed using MATLAB programming. This system will be developed contains all these elements:

- Design high performance computing techniques for computer modeling, data visualization, and interpretation. A particular application area is bioheat transfer modeling of biological bodies.
- Have AI element aspect such as cognitive science, decision making and intelligent multimedia

1.4 Aim of project

The aim of this system is to show the effect of bioheat equations on the thermal states of biological tissues and to predict the effects of the thermal physical properties on the transient temperature of tissues and damage function. This system can be very beneficial in widening the idea of clinical thermal technology and thermal medical practices.

1.5 Report Overview

Chapter 1- Introduction

This chapter is an overview of the project's proposal. This includes the objectives, scope, aim, the importance, and definition of project.

Chapter 2- Literature Review

This chapter includes the literature review of the other works on associated issues and fields of interest.

Chapter 3- Methodology

This chapter identifies and provides the clarification on the methodology approach that will be used in this project and methodology to solve the bioheat equation.

Chapter 4- System Analysis

A detailed analysis of the system development tools are covered which include the practicality and effectiveness of the chosen tools use in this project.

Chapter 5- System Design

This chapter describe the fundamental design such functional design, non-functional design and also the user interface.

Chapter 6- System Implementation

This chapter reviews on the conversion of system requirements into program codes.

Chapter 7- System Testing

This chapter describes the testing conducted to determine the errors that occur until the system is free from errors.

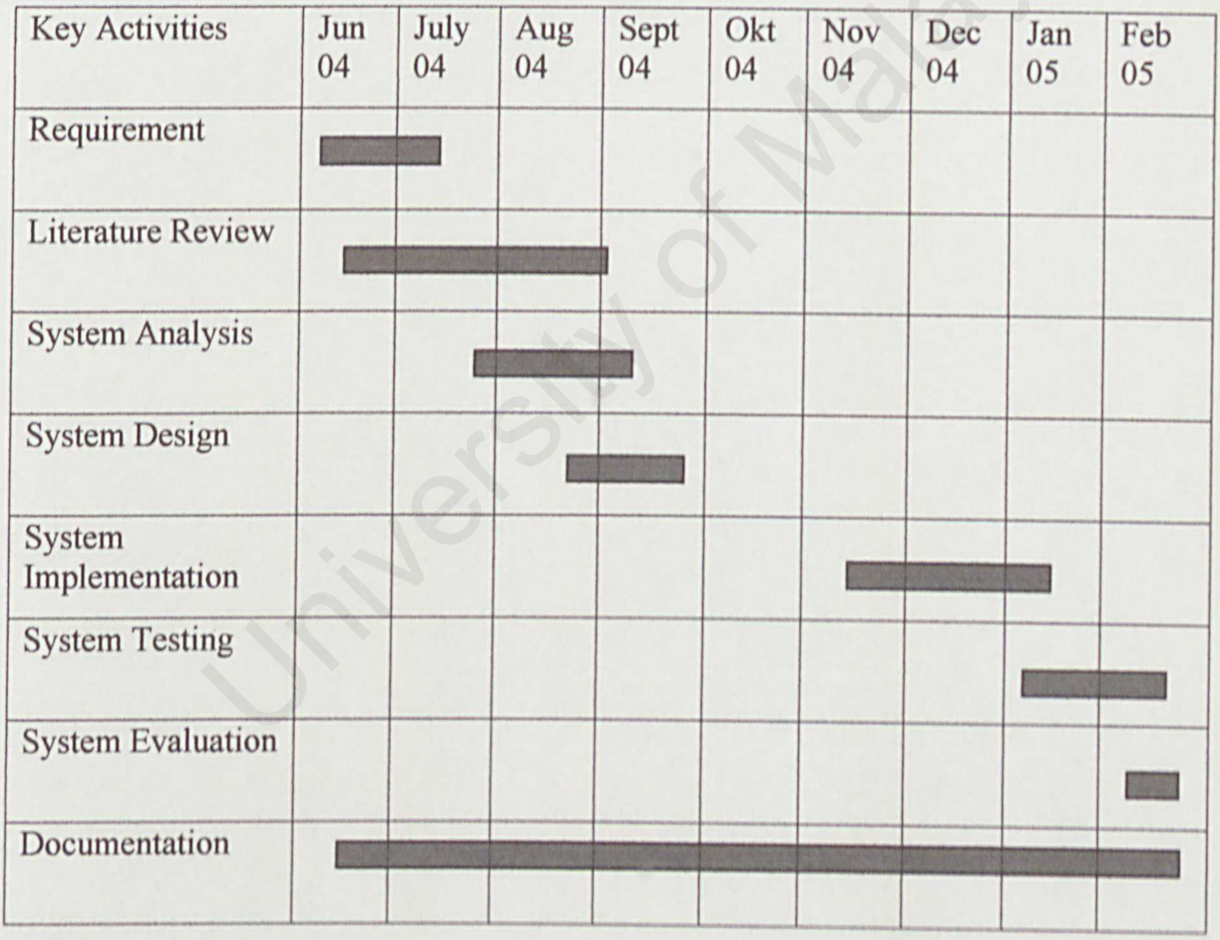
Chapter 8- System Evaluation

This chapter covers the system strength and limitations.

1.6 Project Schedule

In order to organize the development phase of the system, a schedule is essential in order to develop the system in a more proper manner where the development phase follows certain time frame allocated. Below is a Gantt chart on the development phase scheduled along the intended time frame for each phase of the system.

Table 1: Project Schedule Visualization of Bioheat process System.



Chapter 2

Literature Review

CHAPTER 2: LITERATURE REVIEW

Before starting to design any system, the very first steps are to come across the literature surveys and gather all the information needed for further development of the proposed system. There are several ways to retrieve this invaluable information from various resources.

2.1 Bioheat thermal process in human body

The blood circulation underneath the skin, local metabolism, and heat exchange between the skin and its environment controls body temperature. Changes in any of these parameters can induce variation of temperature and heat flux at the skin surface, reflecting the physiological state of human body. Temperature is a measure of the tendency of an object to spontaneously give up energy to its surrounding. When two objects are in thermal contact, the one that tends to spontaneously lose energy is at the higher temperature. Bioheat modeling is skin burns is the one of the application in heat transfer analysis.

Heat transfer in human tissues involves complicated process such as heat conduction in tissues, heat transfer due to perfusion of the arterial-venous blood through the porous of the tissues (bio-convection), metabolic heat generation, and external interactions.

Modeling heat transfer within the body requires formulating equations (named 'bio-heat transfer equations') for heat transfer phenomena within a tissue and assuming a simplified geometric body. Such thermal models have been developed for a wide variety of purposes: the analysis of hyperthermia, the prediction of thermal physiological responses under a severe condition, and the evaluation of the comfort of a thermal environment.

Skin surface temperature is greatly influenced by thermal environmental conditions. Therefore, in order to detect and evaluate an abnormal area from specific colour, eliminating this influence is required.

2.2 Bioheat equation

The thermal structure of the superficial tissues described above can be used as a basis for calculating tissue temperature profiles and for determining responses to transient changes in surface conditions. Here a one-dimensional solution to this problem is provided.

$$\rho c\, \partial T/\partial t = \mathrm{div}\,(k \,\mathrm{grad}\, T) - C_b W (T - T_b) + Q_e \qquad \text{Equation (1)}$$

The term on the left-hand side of the equation is the rate of change of thermal energy contained in a unit volume per unit time. On the right-hand side the three terms represent the rate at which thermal energy enters or leaves the unit volume in unit time by conduction, perfusion and metabolism respectively. This heat transfer equation first suggested by Pennes (1948) is still widely used for heat transfer in biological tissues although it does presuppose an unrealistic degree of tissue homogeneity. Recently modifications have been suggested (Lagendijk 1987, Weinbaum *et al* 1984) which go some way in dealing with the added complexities of local variations in vascular geometry and blood temperature. The main features Pennes's bioheat transfer model are simple, based on uniform perfusion and it is not valid for all tissues.

Setting the Parameters

There are nine parameters that need to be set to define the transport problem. The lines containing the parameter assignments appear in the first cell, at the beginning of the notebook. Each parameter is described briefly below. Also given are the current values of each parameter.

ρ density of tissue

c specific heat of tissue

t time

Cb specific heat of blood

T tissue temperature

Tb blood temperature

w perfusion rate

κ thermal conductivity of tissue

Q_e body heating coefficient

2.3 Hyperthermia

Hyperthermia is heat treatment for cancer. One problem with treating cancer successfully is the fact that cancerous cells are very difficult to target specifically. In most respects, they are like normal cells, and even if they are not, they can hide the differences. Raising the temperature of the tumor is one way to selectively destroy cancer cells. Hyperthermia is usually classified as local, regional, or whole body. Hyperthermia is dependent on both temperature and time.

Hyperthermia cancer therapy is defined as selective tumor cell killing by local, regional or whole body heating to temperatures between 41°C and 45°C for a period ranging from minutes to a few hours and in opposition to the body's control processes whose purpose is to maintain the temperature around the normal set. Whole body hyperthermia (WBH) implies maintaining the body temperature at up to 42°C. For regional and local hyperthermia, the aim is to achieve temperatures in the range 42° and 45°C. In regional hyperthermia, large portions of the trunk or limbs are heated and often a difference in perfusion of the tumor and normal tissue is relied upon to produce a temperature differential. In localized hyperthermia a smaller volume of tissue local to the tumor is heated.

Bioheat transfer

The objective of hyperthermia in cancer therapy is to raise the temperature of cancerous tissue above a therapeutic value while maintaining the surrounding normal tissue at sublethal temperature values. It has been suggested that numerical modeling of the induced temperature distributions would yield a more complete description of the three dimensional temperature distributions. Modeling the hyperthermia induced temperature distribution requires an accurate description of the mechanism of bioheat transfer. It is well known that blood flow affects the thermal response of living tissues.

The heat exchange between the living tissues and the blood network that passes through it depends on the geometry of the blood vessel, the blood flow through it, and the properties of the blood and the surrounding tissue. For example, it has been demonstrated that the presence of large vessels in a heated volume with blood entering at systemic temperature can be an important source of tissue temperature non-uniformity and possible hyperthermia under dosage. Considering all the above, tremendous efforts were focused on describing the temperature field around blood vessels.

The theoretical analysis of heat transfer and the interpretation of the heat clearance measurements started with the use of the simplified bioheat equation derived by Pennes, (1948). The bioheat equation is a modification of the well-known transient heat conduction equation in which the convective effects of the moving blood are treated as a volumetric isotropic heat source. The metabolic heat generation can be also included, if needed.

Bioheat transfer equation:

$$\rho c \, \partial T / \partial t = \mathrm{div}(k \, \mathrm{grad} \, T) - Cb \, W (T - Tb) + Qe \qquad \text{Equation (1)}$$

During hyperthermia treatment the tissue temperature grows up to the upper boundary of the tissue surviving, i.e. up to 44- 46°C, moreover, during a thermotherapy course based on the thermal tissue coagulation the temperature can attain values about 100 °C. So the question of whether the cellular tissue undergoing so strong heating can be described in the framework of the passive medium model is not evident. Therefore the thermal properties of cellular tissue under local strong heating deserve individual investigations to clarify if the physical background of the bioheat transfer theory has to be modeled. In particular, the fact that heat propagation in cellular tissue can exhibit anomalous properties was noted in.

2.4 Visualization

2.4.1 Overview

Visualization simply means presenting information in pictorial form and using human recognition capabilities to detect patterns. Scientists, engineers, medical personnel, business analysis, and others often need to analyze large amounts of information or to study the behavior of certain processes. Numerical simulations carried out on supercomputers frequently produce data files containing millions data values. Similarly, satellite cameras and other resources is a large data files that faster than it can be interpreted. To scan these large sets of numbers to determine the relationship is an ineffective process. But if the data are converted to a visual form, the patterns are often immediately clear. To produce graphical representation for scientific, engineering, and medical data sets and processes is generally referred to as scientific visualization.

There are many different kinds of data sets, and an effective visualization depends on the characteristics of the data. A collection of data can contain scalar values, vectors, high-order tensors, or any combination of these data types and data sets can be 2D, or 3D and the colour is just one way to visualize a data set.

Other techniques in visualization are like contour plots, graphs, charts surface renderings, and visualizations of volume interiors. Image processing techniques are combined with computer graphics to produce many of the data visualization.

The visualization of the volumetric data has aided many scientific disciplines ranging from biomedical sciences to distance learning to geophysics. The diversity of the fields and the growing reliance on visualization has led to its importance. There is so much emphasis on visualization as it often the most intuitive mode of analysis. Currently a lot of research is being done for implementing specialized visualization system.

2.4.2 *Visualization concept*

Visualization is a formation of mental visual images, the act or process of interpreting in visual terms or of putting into visible form (Colin, 2000). The scientific visualization is the formal name given to field in computer science that encompasses user interface, data representation and processing algorithm, visual representation, and other sensory presentation such as sound and touch.

Visualization is more than a method of computing. It is process of transforming information into a visual form enabling the user to observe the information. On the computer science side, it uses techniques of computer graphics and imaging. Besides relying on visual computing and display, it involves human beings. Thus, we need to take into account human perception and cognitive capabilities, human variations, task characteristics and decision-making. Successful visualizations can reduce the time for the user to get the information, make sense out of it, and enhance creative thinking. In contrast with most data used in scientific visualization, information is usually non-spatial or abstract. To create visualization, one needs to map the information into physical space that will represent relationships contained in the information faithfully and efficiently. This could enable the observer to use his/her innate abilities to understand spatial relationships. Finding a good spatial representation of the information at hand is one of the most defunct tasks in visualization of abstract information.

There are several different aspects to user interface for a data visualization system. These include the following:

- interaction with the visualization process such as modifying parameters or changing the method of data analysis to look at different views of the data.
- interaction with the original data collection or computation and the ability to modify the model , or even the problem.

The reason for having visualization system is to help people solve problem. Thus, the area of cognitive psychology, which is the study of how people solve problems, is highly relevant. It has been postulated that the semantics of the representation of a problem may determine how difficult the problem is to solve. For example when people are given isomorphic problems (identical in form) but with different semantic representations, there is little carry over in the problem solution process. This means that what the user learns in solving the first problems is not used in solving the second problem, even though they are identical in form, but not in representation.

2.4.3 Data visualization techniques

i. Isosurfaces and Contours

This display technique is best suited for geographical or other physical object depictions. Contour lines connect data points that have the same value for a particular parameter in a region of values. Isosurface is a 3D surface contour, where at each point on the surface, the value of the data is the same.

ii. Volume rendering

One of the most active areas in advanced data visualization is volume rendering. Volume rendering is the process of projecting multidimensional data set onto a two-dimensional image plane in order to gain better understanding of the internal structure of the volumetric data visualization. This technique is most commonly used in the medical field, geosciences, astrophysics, chemistry, mechanical and other engineering fields.

iii. Colour Mapping

Colour maps present a relationship between a range of data values and a range of colours. In this process, each colour is mapped to either a specific data value or a range of data values. Often a continuous colour gradient, or colour spectrum, is used in colour maps. Colour mapping is very useful when applied in conjunction with other visualization techniques. For example, a colour map can be used with a three-dimensional plot in order to display a relationship four variables.

iv. Vector Field Representation

Vector field representation uses a broad set of techniques to depict the magnitude of data or a direction of flow. These techniques also allow users to depict two data attributes in a single point. Some of the popular vector field techniques are streamlines and glyphs. Streamlines illustrate a general flow and are the lines that are tangential to a velocity field at each point. Glyphs are generic visual objects, such as a sphere, that are used to represent data.

v. Voxelisation

Voxelisation is the process of producing 3D data from an object description like polygonal meshes, so that each voxel has a value. Voxel (volume element) is the name given to a value in 3D space. The data can then be rendered using a volume visualization technique to produce an image of the original object. Voxelisation is the process of converting an object of one description into volume data. Appropriate volume visualization techniques can be applied to any data.

2.5 Artificial intelligent aspect

Artificial intelligent (AI) is a branch of computer science applying human intelligence to computer system.

2.5.1 Different user

Different user whether expert or non-expert can use this system will make the system is intelligent. The expert is a shown how will the system go with different point of view. Here three different users had been used, theoretical modeling of bioheat process, doctor, and patient. Under patient record, doctor may have information like sickness, normal or abnormal temperature using height 3D, colour, contour, and arrow technique visualizations. For a patient, they may have information like sickness, normal or abnormal temperature using color visualizations.

2.5.2 Cognitive science principle

Colour is a visualization techniques used to convey more information. Many applications used the colouring approach since information can be displayed attractively to users and can often improve task performance. The appropriate use of colour is very important for effective visualization because the human eye is least sensitive to the colour (Collin, 2000) Trichromacy theory explains that most important fact about colour vision is that we have three distinct colour receptor called cones in our retinas that are active at normal light level.

Visualization amplifies cognition. About six major ways in which the visualizations can amplify the cognition are:

- increasing the memory and processing resources available to the users.
- used visual representations to enhance the detection of patterns
- enabling perceptual inference operations
- used perceptual attention mechanisms for monitoring
- encoding information in a manipulability medium.

This visualization can allow patterns in the data to reveal themselves and it allow some inferences to be done very easily. It also allow the environment to store details like map close to where they need to be used, reduce data search by grouping or visually relating formation where they can compact information into a small space. Besides that, it also allows patterns in the data reveal themselves and allows some inferences done easily.

2.5.3 Decision-making

The management of this system can involve computer's capability of performing rapid calculations of the bio-heat equation and data comparison could be used to produce meaningful information for management to the user whether to non-expert user or expert user. This system can do a decision-making process to get know what the user status in temperature based on information of their knowledge.

As the system move toward decentralized decision-making, give the users access to information they need to make decision. This is to get the solution the bioheat process. Non-management user also benefit by having information available through modeling and visualization from the information.

2.5.4 Memory and knowledge

Colour mapping can attach the meaning of the temperature in-patient's which is will store at long-term memory. Learning colors because it will works with the semantic memory. Semantic memory contains world knowledge, not skills. This knowledge is generic and context independent such as colour of the temperature and boundary of temperature. Semantic use the perceptual categories such as colour are organized such that prototypes for various colours exist.

2.5.5 Intelligent multimedia

Today multimedia in its different forms penetrates a lot of different communication environment from a technical point of view multimedia is based on networked communication (e.g. www) as well as digital store media (e.g. CD-ROM). In the literature we can find different definitions of multimedia, one of the definition is, according to Fibiger (n.d), multimedia is the combination of timer-based media, such as voice, animation and video- a lord with space-based media- such as text, graphics and images.

Multimedia allows the process of learning to become more exciting and experienced. It is also helps the person to understand concepts faster and easier. The usage of multimedia has some importance in the medical process. It gives an opportunity to the doctor and patient to get knowledge about the human body temperature.

2.5.6 Numerical method

Partial differential equation such as bioheat equation using Matlab is one part of the numerical method that include in AI aspect. The PDEs have capability to solve many problem areas such as engineering problem including heat conduction.

2.5.7 Visualization

Visualization has two aims that are perception and interpretation. Interpretation aims are defined by the viewer(s), for example identify objects, compare values, distinguish objects, and categorize objects. Types of interpretation are supported by classification of data (temperature value) e.g. low, normal, and high temperature. It can generate meaningful information. Besides that, the user can understand how perception works, our knowledge can be translated into rules for displaying information. In addition, visualization can reduce time for user to get the information.

2.6 Matlab

2.6.1 Overview

Matlab is an acronym for Matrix Laboratory and high performance language for technical computing. Matlab can be used to represent a physical system or a model. It integrates computing, visualization and programming in a user-friendly environment where problems and solution are expressed is familiar mathematical notation. Typical uses of Matlab include:

1. Math and computation
2. Algorithm development
3. Modeling, simulation and prototyping
4. Data analysis, exploration and visualization
5. Scientific and engineering graphics
6. Application development, including graphical user interface building

Matlab is an interactive system which basic data element is an array that does not require dimensioning. Many technical computing problems, especially those involving matrix and vector formulations can be such as C or Fontran.

In university environment it is a standard instructional tool for introductory and advance courses in mathematics, engineering and science. In the industry, it is used for high-productivity research, development, and analysis.

Matlab also has application specific solutions called toolboxes. Toolboxes are comprehensive collection of Matlab functions (M-files) that extend the Matlab environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural network, fuzzy logic, wavelets, simulation, and others.

2.6.2 Matlab and other platforms

Matlab allows interaction with data and programs external to its environment. It provides an Application Program Interface (API) to support these external interfaces. The functions supported by the API include:

1. Calling C or Fontran programs from Matlab
2. Importing and exploring data to and from the Matlab environment
3. Establishing client/server relationship between Matlab and other software programs.

2.6.3 The Matlab array

The Matlab language works with only a single object type: array. All Matlab variables including scalar, vectors, matrices, string, cell arrays, structures and objects are stored as arrays.

Matlab data types include:

1. Complex double-precision matrices
   - These matrices are of type double and have dimension of m-by-n, where m is the numbers of rows and n is the number of columns. The data is stored as two vectors of double-precision numbers – one containing real data and the other imaginary data.
2. Numeric matrices
   - These are single-precision, floating print, and 8-, 16-, and 32-bit integers,

both signed and unsigned. The data is store in two vectors in the same manner as double-precision matrices.

3. Strings

   - Strings in Matlab are of type char, and are sound just as unsigned 16-bit integers are, except that no imaginary data component exists. Each character in the string is stored as 16-bit ASC11 Unicode.

4. Cell arrays

   - Cell arrays are a collection of arrays, where each array is referred to as a cell. This allows arrays of different types to be stored together. Each cell can be of any supported data type, even another cell array.

5. Multi-dimensional arrays

   - Matlab arrays of any type can be multi-dimensional. A vector of integers is stored where each element is the size of the corresponding dimension. The storage of the data is the same as matrices.

6. Logical arrays

   - Any noncomplex numeric or sparse array can be flagged as logical. The storage for a logical array is the same as the storage for a non-logical array.

2.6.4 *Matlab graphics*

Matlab has graphics features for visualizing data and preparing presentation graphics. It has routines for building 2D and 3D graphic structures such as line plots, contour plots, mesh and surface plots, and animation. In addition to this colour, shading, axis labeling and general appearances can be controlled. Lighting effects, patches, and control of aspect ratio and display size enhance data output in Matlab.

2.6.5 *Partial Differential Equation Toolbox*

PDE Toolbox is a graphical user interface (GUI). `pdetool` provides the graphical user interface (GUI) for the PDE Toolbox. The GUI helps you to draw the 2-D domain and to define boundary conditions for a PDE problem. It also makes it possible to specify the partial differential equation, to create, inspect, and refine the mesh, and to compute and display the solution from the GUI.

`pdetool` contains several different modes:

In *Draw mode*, you construct a Constructive Solid Geometry model (CSG model) of the geometry. You can draw solid objects that can overlap. There are four types of solid objects:

- Circle object - represents the set of points inside a circle.
- Polygon object - represents the set of points inside the polygon given by a set of line segments.
- Rectangle object - represents the set of points inside the rectangle given by a set of line segments.
- Ellipse object - represents the set of points inside an ellipse. The ellipse can be rotated.

Typing a set formula can combine the solid objects. Each object is automatically assigned a unique name, which is displayed in the GUI on the solid object itself. The names refer to the object in the set formula. More specifically, in the set formula, the name refers to the set of points inside the object.

In *boundary mode,* you can specify the boundary conditions. You can have different types of boundary conditions on different boundaries. In this mode, the original shapes of the solid building objects constitute borders between sub domains of the model. Such borders can be eliminated in this mode. The outer boundaries are color coded to indicate the type of boundary conditions. A red outer boundary corresponds to Dirichlet boundary conditions, blue to generalized Neumann boundary conditions, and green to mixed boundary conditions. You can return to the boundary condition display by clicking the $\partial\Omega$ button or by selecting Boundary Mode from the Boundary menu.

In *PDE mode*, you can specify the type of PDE problem, and the coefficients *c, a, f,* and *d.* You can specify the coefficients for each sub domain independently. This makes it easy to specify, e.g., various material properties in one PDE model. The PDE to be solved can be specified by clicking the PDE button or by selecting PDE Specification from the PDE menu. This brings up a dialog box.

In *Mesh mode*, you can control the automated mesh generation and plot the mesh. An initial mesh can be generated by clicking the Δ button or by selecting Initialize Mesh from the Mesh menu. The initial mesh can be repeatedly refined by clicking the refine button or by selecting Refine Mesh from the Mesh menu.

In *Solve mode*, you can specify solve parameters and solve the PDE. For parabolic and hyperbolic PDE problems, you can also specify the initial conditions, and the times at which the output should be generated. For eigenvalue problems, the search range can be specified. Also, the adaptive and nonlinear solvers for elliptic PDEs can be invoked. The PDE problem is solved by clicking the = button or by selecting Solve PDE from the Solve menu. By default, the solution is plotted in the `pdetool` axes.

In *Plot mode* you can select a wide variety of visualization methods such as surface, mesh, contour, and quiver (vector field) plots. For surface plots, you can choose between interpolated and flat rendering schemes. The mesh can be hidden in all plot types. For parabolic and hyperbolic equations, you can animate the solution as it changes with time. You can show the solution both in 2-D and 3-D. 2-D plots are shown inside `pdetool`. 3-D plots are plotted in separate figure windows. Different types of plots can be selected by clicking the button with the solution plot icon or by selecting Parameters from the Plot menu. This opens a dialog box.

2.7 Summary

Many problems are encountered in the field of volume visualization. Some of these problems themselves have branched into areas of research. These include:

i. Volume visualization system has to be such that it unites numerous visualization methods.

ii. Visualization from complex data sets.

iii. Aspect of color that can get important knowledge.

iv. Knowledge of human perception can lead to more effective visualizations.

v. Bioheat process in the human body.

vi. Hyperthermia as a heat treatment for cancer.

Chapter 3

Methodology

CHAPTER 3: METHODOLOGY

3.1 Development methodology

A system development methodology or also known as process model is a collection of procedures, technology, tools and documentation aids which help system developers in their task of implementing a new information system. It consists of a set of phases, which consists of a set of sub phases. This shows the way in applying the set of software process activities and associated result towards producing a software product. It defines the stages of a system development project, specifies the task to be carried in and out, and the output is expected from each stage. Methodology provides guideline for the developers and helps them to plan, manage, control and evaluate info system project.

There are many types of development model in the software engineering, such as waterfall model, waterfall with prototyping model and spiral model. A good methodology, which is able to provide the effective ways of system development, is best defined before the project starts and then becomes the framework to development staff. Below are some benefits offered by a good methodology:

- Provides a standard framework that the developer does not have to reinvent the wheel for each project
- Each method or tool in the methodology results in successful completion of each development task
- Increase the system quality by enforcing the developer to produce flexible system and adequate documentation
- Provides better understanding of user needs and validation of user needs

- Provides the management with tools to review project progress and checklist to access tasks and deliverables
- Improves communication among management, analyst, programmers, users and other stakeholders by providing a communication base
- Facilities planning and controlling the project

I have decided to use the *Waterfall Model* as my system process approach.

3.1.1 Waterfall Model

The waterfall model is also called the "classic life cycle" or the "linear sequential model". The stages of the waterfall model are performed sequentially, in a systematic fashion. Only after a stage is completed can the next stage begin. However, if errors are detected during any stage, one can return to the previous stage for corrections.

The waterfall model was derived from engineering models to put some order in the development of large software products. It consists of different stages, which are processed in a linear fashion. Compared to other software development models it is more rigid and better manageable. The waterfall model is an important model, which is the basis of many other models, however for many modern projects it has become a little outdated. It is still wildly used.

The Waterfall Model was chosen because of the following reasons:

- Very structured

  The system is design using a logical flow.

- Predictable

It allows estimation of the completion of each stage so that the system can be developed within the time frame given. Involve user's participation. Require information gathering form the user in order to develop a system hat meet user needs to a greater extend.

- Good visibility

All the requirements can be identified and well defined.

- More efficiency

The time and resources can be well determined in order to enable developers to manage the project more efficiency.

The Waterfall Model is shown as below:

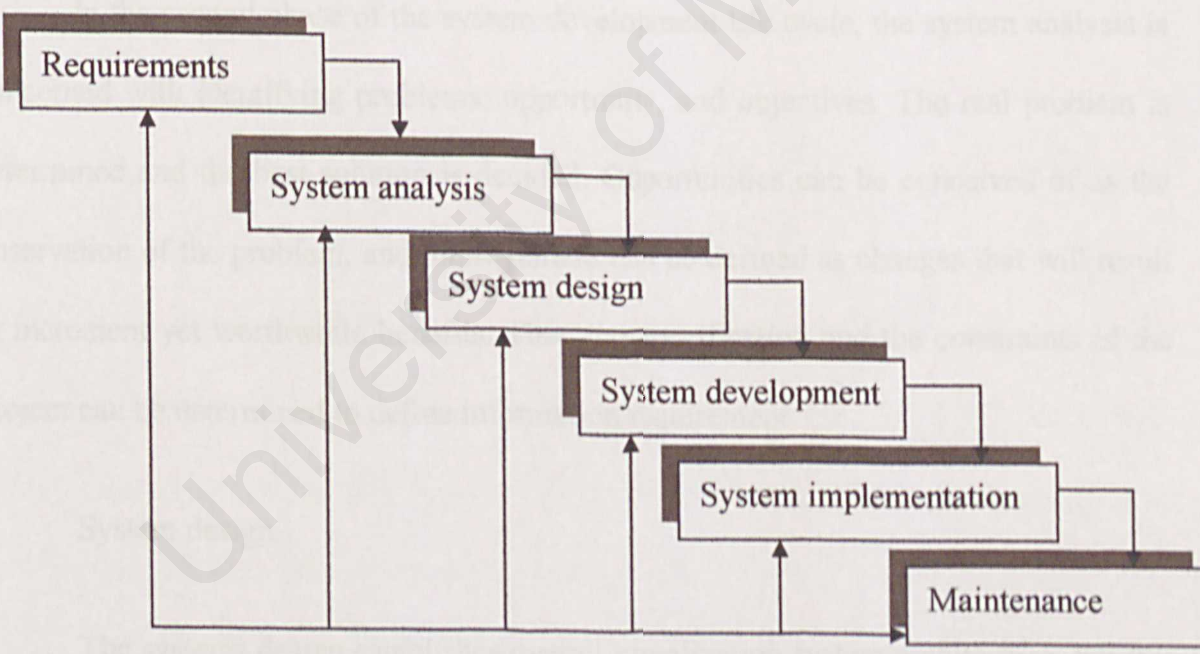


Figure 3.1: The Waterfall Model

The waterfall model encompasses the following activities:

1. Requirements

This first stage is the requirements gathering stage to determine requirements of the system. To developing the visualization system, the requirements gathered would include the interaction between subsystem, functionality, behavior, performance, interface, and constraints of the system. The requirements including functional and non-functional are documented and reviewed. Besides that, software and hardware requirements during the development stage are also have to identify.

2. System Analysis

In the second phase of the system development life cycle, the system analysis is concerned with identifying problems, opportunity, and objectives. The real problem is determined and the best solution is decided. Opportunities can be conceived of as the observation of the problem, and improvement can be defined as changes that will result in increment yet worthwhile benefits. Then the specification and the constraints of the project can be determined to define information requirement.

3. System design

The systems design establishes overall visualization system architecture. For this project, system design focuses on distinct attributes of the modules in visualization program. The main page appearance of the visualization subsystem was designed in this stage. Thus, the flow chart of the system, interface representation, and technical of visualize are also required in this stage. In addition, the project system design also includes transforming the requirements into a representation that can be assessed for quality before the code generation (implementation stage) begins.

4. Implementation and unit testing

During this stage, set of programs or program units section in visualization modules like User Section, Visualization section and Executive Information System will be create in the system based on the project system design. After code has been generated, unit testing is performed to verify that each unit meets its specification.

5. Integration and system testing

This stage tests the complete of visualization of bioheat system. All the program units tested as a complete system to verify that the software requirements have been met. The system is delivered to the user after the testing process.

6. Operation and maintenance

Maintenance takes place after the system is put into practical use. Maintenance involves correcting errors missed in earlier stages of the life cycle, improving the system implementation, adding performance or functional enhancements or making changes due to accommodate changes in the software external environment for overall this system.

3.2 Methodology of calculating equation of bioheat process.

In another approach using the pdetool GUI, similar mathematical formulation and boundary conditions are applied. This approach is perhaps easier to grasp and can be taught as part of the heat transfer. However, care should be taken to balance the skill of solving parabolic PDE numerically with that of using this 'black-box'.

The estimation of temperature profiles inside a human body is performed by developing a numerical programming using MATLAB and applying its PDE Toolbox (pdetool) Graphical User Interface (GUI). There are 4 types of PDEs which is hyperbolic, parabolic, elliptic and eigenmodes. From the pennes' equation, the equation of parabolic is likely the same. I choose to use the parabolic equation and heat transfer to solve this equation. The Parabolic and heat transfer PDE:

Rho*C*T' – div (k*grad (T)) = Q+h*(Text–T)

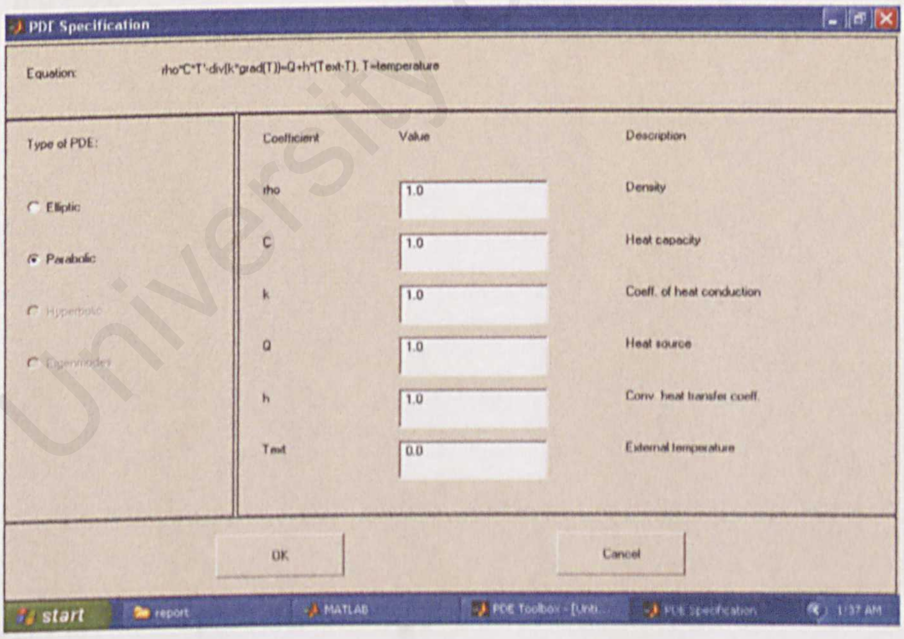


Figure 3.2: Options in the equation solver.

In this work, the thermal parameters which is coefficient of heat conductivity *k*; thermal capacity *C*, density *rho*, heat source Q, temperature T, external temperature Text and conductivity heat transfer coefficient h. The resulting parabolic PDE of the temperature *T with* respect to this parameter, it will display the visualization in many ways that you want after insert the values to the equation.

There are several general step to any PDE problem, and there are a few more to solving them numerically. These are:

- defining the domain of the problem in space (i.e. the geometry- draw mode)
- defining the time-dependence of the problem
- defining the initial and/or boundary conditions
- setting up the proper PDE for solution
- choosing the "coefficients" or physical properties of the system
- defining the "mesh" or set of sub-domains on which to numerically solve the PDE

Chapter 4

System Analysis

CHAPTER 4: SYSTEM ANALYSIS

As is progress from the literature research and review stage, the next phase is to perform a through and detailed analysis of the system development. Emphasis will be on the functional and non-functional requirements of the system development needs. Thus I can say that system analysis is a stage of gathering, analyzing, and finalizing or determine the problem scope and the objective of goals, which the system will have to achieve.

4.1 Technique for requirement elicitation

Capturing requirement of a system or in a more formal note-eliciting requirement seems to be a very straightforward process. However, it does face several barriers, which complicates the whole process. The problems are many and one of it could be that the users do not know what they want, or that the analyst thinks they understand user problems better than user do. Nevertheless, there are techniques that have proved effective in addressing these problems.

Information from internet source

This is main source, it is easy and quick to get information about bio-heat process. The way to search the reference of the bioheat process is using search engine like Yahoo, Google, and AltaVista.

Printed material

The printed material that was used is mainly journal and books from the Main Library of Malaya University. Especially the textbooks and guide books a programming language that was from previous years of studying in the field Artificial Intelligent and about heat conduction and thermal process. However, information knowledge was also gained from journals and conference paper.

The reports on the previous projects also help a lot especially in the structure of the documentation. It helps a smoother flow to the documentation by giving ideas on the structure and contains.

4.2 Analysis Procedures

An analysis procedure is important in order to identify the various requirement and objectives that need to be met by the user. The outcome of the analysis will serve as guideline for the developer during the design on what and how the system has to function in order to fulfill the user require. Listed below are the procedures for system analysis:

i) Problem Identification

ii) Evaluation And Synthesis

iii) Modeling

iv) System Requirements And Specification

4.2.1 Problem Identification

Essentially the first phase in the system analysis procedure, the problem identification stage is being carried out in order to recognize and identify the objective of the system and the goals that the system need to meet in order to satisfy the user needs. In visualization of bioheat process module the problem identification is that the system has to perform the visualization temperature of human body in many ways. The main goal that needs to be met by the system is to be able to function in a real time manner as well as to provide the user a reliable, user friendly and efficient functionality.

4.2.2 Evaluation and Synthesis

In this stage, analyzing of problems has to be done by dividing the problem scope into smaller parts so that the problem can be tackle one by one. By doing this, we can have a better view and understanding on the problem scope and eventually easier to solve.

The following are problems that needed to be considered for system requirement:

i) Consideration of programming language that will suite the development of the system.

ii) Consideration of how to manage the processing and data flow of the system.

iii) Consideration on direct to solve the equation of bio-heat process.

iv) Consideration of combination of many visualization.

4.2.3 Modeling

By using a graphical representation on the data flow process, we can better understand how the system actually works. A graphical model such as flow chart can be present the flow of the system is built.

The analysis here has the following main objectives:

- To solve for the bioheat equation of human body temperature
- To determine the distribution of minimum temperature and maximum temperature

The basis for modeling is Pennes' bio-heat-transfer equation, which is equipped with a temperature-dependent blood perfusion. The purpose of Pennes' study was to evaluate the applicability of heat flow theory to the forearm in basic terms of the local rate of tissues heat production and volume flow of blood. An important feature of

Pennes' approach is that his microscopic thermal energy balance for perfuse tissues is linear, which means that the equation is amenable to analysis by various methods commonly used to solve the heat-conduction equations. For example, I used the Pennes' equation to analyze and developed a few part in human body thermal model. The equation proposed by Pennes is now generally known either as the bioheat equation or as the Pennes equation.

The equation is:

Table 4.1 The equation.

Equation		
	Convention	Description
	pdetool	Rho**C**T'– div (*k**grad (T))=Q +h * (Text –T) Where: *k* coefficient of heat conductivity *C* thermal capacity *rho* density *Q* heat source T temperature Text external temperature h conductivity heat transfer coefficient

	Mathematical equation	$\rho c \partial T/\partial t = \mathrm{div}(k\ \mathrm{grad}T) - c_b W(T - T_b) + Qe$ where: ρ density of tissue c specific heat of tissue t time T tissue temperature κ thermal conductivity of tissues c_b specific heat of blood T_b blood temperature W mass flow rate of blood per unit volume of tissue Qe deposited by an electric field E in tissue with electric conductivity

Limitations of Pennes' Model

The limitations of this model arise from the erroneous view of the heat transfer process and its anatomical location. The thermal equilibration length is defined as the length at which the difference between the blood and tissue temperature decreases to 1/e of the initial value. The limitation of this model is that given the detail required, the model is not easy to implement. Also, the perfusion conductivity term is difficult to evaluate.

4.2.4 System Requirement and Specification

The requirement is a characteristic or descriptions that play in system development to complete a system in execution as suggested. It is not only explaining a flow of input and output information about the system but also explaining the restriction too in system execution.

To get exact requirement, each process need a repetition and should be involve a feedback from end-user and system developer. An exact requirement is important to ensure that the system executed normally. For the system requirement specification there have two type of requirement.

There are 2 types of requirements, which are:

i) Functional requirements

ii) Non-Functional requirements

4.2.4.1 Functional Requirement

A functional requirement refers to the interaction between the system and the working environment the system resides in. It also describes how a system should behave and perform their task given a set of input or stimuli. Stated below are the components in functional requirement analysis:

Visualization module

This section refers to the visualization modules of this system. We can say that this section has the foremost of importance among the functionality requirements for it processes the user request and therefore generate the intended output. The system processing has two modules, which also represents each visualization task category as listed below:

- Perform mathematical computations

  The system must able to perform all the mathematical calculations required by the partial differences equations (PDE). The system must be able to generate accurate results for every calculation.

- Use interface Module

  Describes the responsible on how the communication between the user with the system in getting information or input from the user for further processing. We can distinguish the main criteria which emerge in this section which are the:

  a) Display Module – front end design or the user interface which serves as the direct interaction phase between the user and the system.

  b) Result Page – page include a listing of the processing results which is performed upon the user request

4.2.4.2 Non-Functional Requirements

Other important criteria to ensure the user satisfied must give an attention. It is not only about the function that is executed by the system, but its need a non-function requirement involved. Non-Functional requirement can be described as constraint where the system must operate to a certain degree of standard of operation. These constraints usually narrow the selection of development tools such as programming language, platform and others. Listed below are the non-functional requirements of the system:

i) Reliability

Reliability refers the extent of the system performance that are expected or desired by the user, which required criteria such as precision and accuracy. Reliability will convince the user on the capability in performing to their expectation as well as providing error-handling capability.

ii) Maintainability

Maintainability refers to the degree which the system can perform its function or adapt to a possibly changing of operation environment. A good maintainability system will be easy to modify and test in future upgrading of the system or correcting the errors or moving the system to other computer system.

iii) Efficiency and correctness

The system can do what the user want when it is needed although it has been used all the time and it can use within any problem.

iv) User Friendliness

Designing of a graphical user interface will eventually enhance user friendliness as well as easier for the user to understand and use the system. Good consideration of user interface design is that the interface must fulfill the following criteria:

a) Consistent or standard – which mean every interface of different module shall look similar in order not to confuse the user.

b) High Degree Of Understandability – Enable easier use of the system.

4.3 Hardware and Software Requirements

Hardware

Hardware requirement refer to the hardware support needed in order to run the system smoothly.

Control Processing Unit	Pentium 4 1.8 GHz
Memory Space HDD	20.0 GHz
Random Access Memory	128 DDRAM
Other requirement	Mouse, Keyboard, CD-ROM, VGA, and sound system

Software

Software Requirement refers to the application or software tools needed in order to develop and run the system at the server side.

Operating System	Windows XP or Windows 2000
Programming Language	Matlab 6.5

4.4 Summary

This chapter mainly deals with the requirement of the system. At the beginning it was explained what technique were used to solicit the system requirement. After that analysis about the equation used to solve this problem. Lists of functional and non-functional requirement were specified. Besides the minimum hardware and software requirement for the system was also mentioned.

Chapter 5

System Design

CHAPTER 5: SYSTEM DESIGN

5.1 Introduction

System design is a phase of the waterfall that entire requirement are translated into system characteristic. The requirements for the system are regarding to the analysis that had been discussed in the previous chapter. System design includes the following issues:

- Main menu module
- Visualization module

5.2 System Functionality Design

5.2.1 System structure charts

There are 2 categories of users. This is a system structure chart for the expert user (doctor). The flow of main program for expert user is:

1. Start
2. Call matlab function such as:
   - defining the domain of the problem in space (i.e. the geometry)
   - defining the time-dependence of the problem
   - defining the initial and/or boundary conditions
   - setting up the proper PDE for solution

- choosing the "coefficients" or physical properties of the system defining the "mesh" or set of sub-domains on which to numerically solve the PDE.

3. Display the result in many ways of visualizations.
4. If the user wants to use the new values, user will return to set the pde again. If not the system will stop.

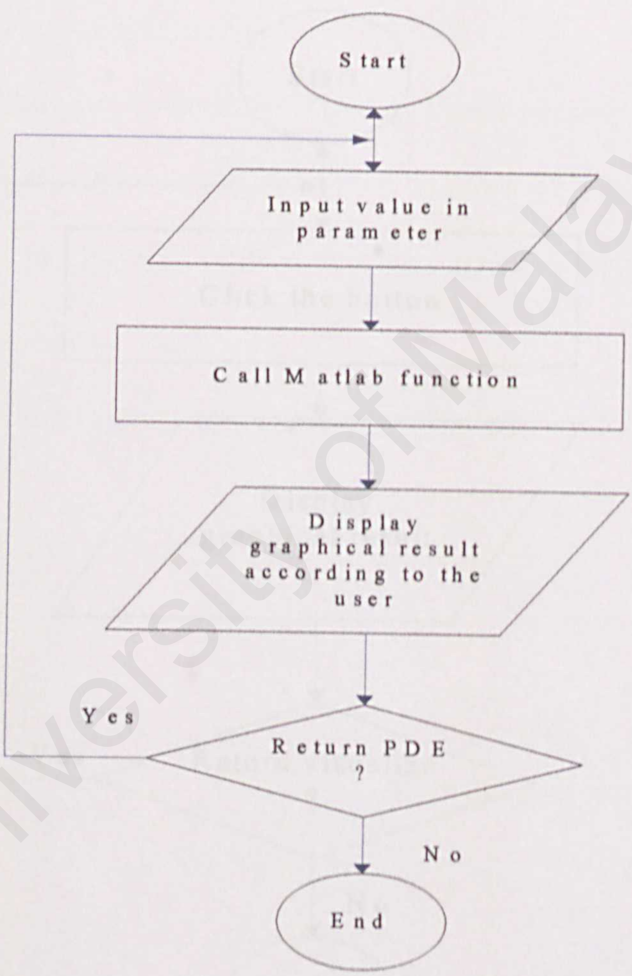


Figure 5.1: The flow diagrams of main program visualization for expert user (doctor).

The flow of main program for non-expert user is:

1. Start
2. Click the button
3. The result will display
4. If the user want to see the other visualization then continue with click the button. If not, stop.

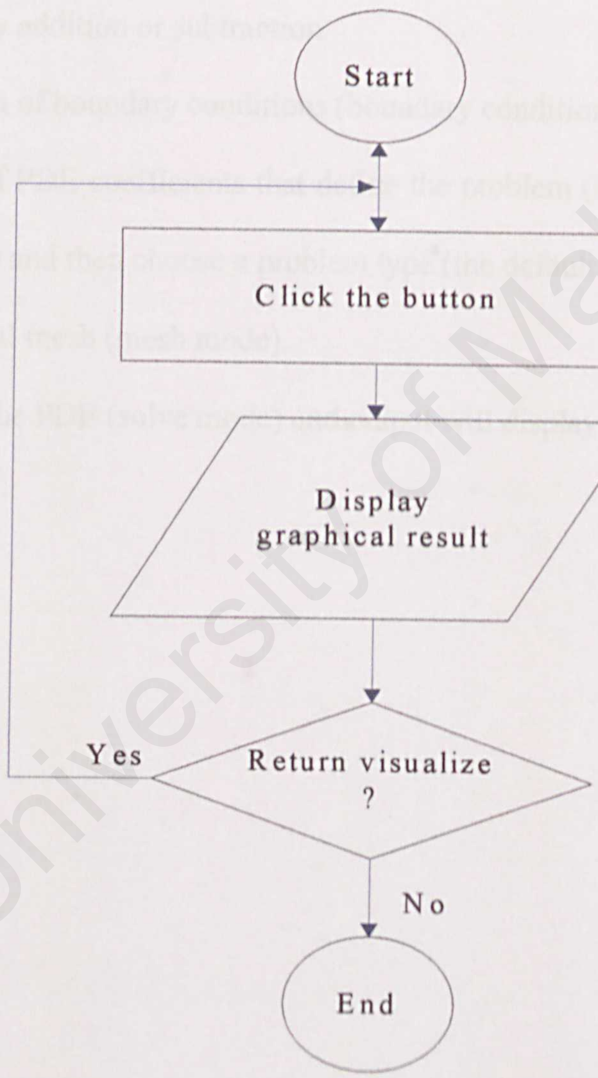


Figure 5.2: The flow diagrams of main program visualization for non-expert user (patient).

The PDE solutions have six steps and corresponding PDE Toolbox usage modes are:

1. Identify the equation
2. Specify the domain (geometry definition)

   Domains are constructed by the addition and subtraction of primitive domains such as rectangles, polygons, and ellipses. To form the desired domain, type in a formula in the set formula box (above the displayed region) to combine the primitives by addition or subtraction.
3. Specification of boundary conditions (boundary condition mode).
4. Selections of PDE coefficients that define the problem (PDE mode). Select *PDE specification* and then choose a problem type (the default is Elliptic).
5. Specify initial mesh (mesh mode).
6. Solution of the PDE (solve mode) and output will display based on users.

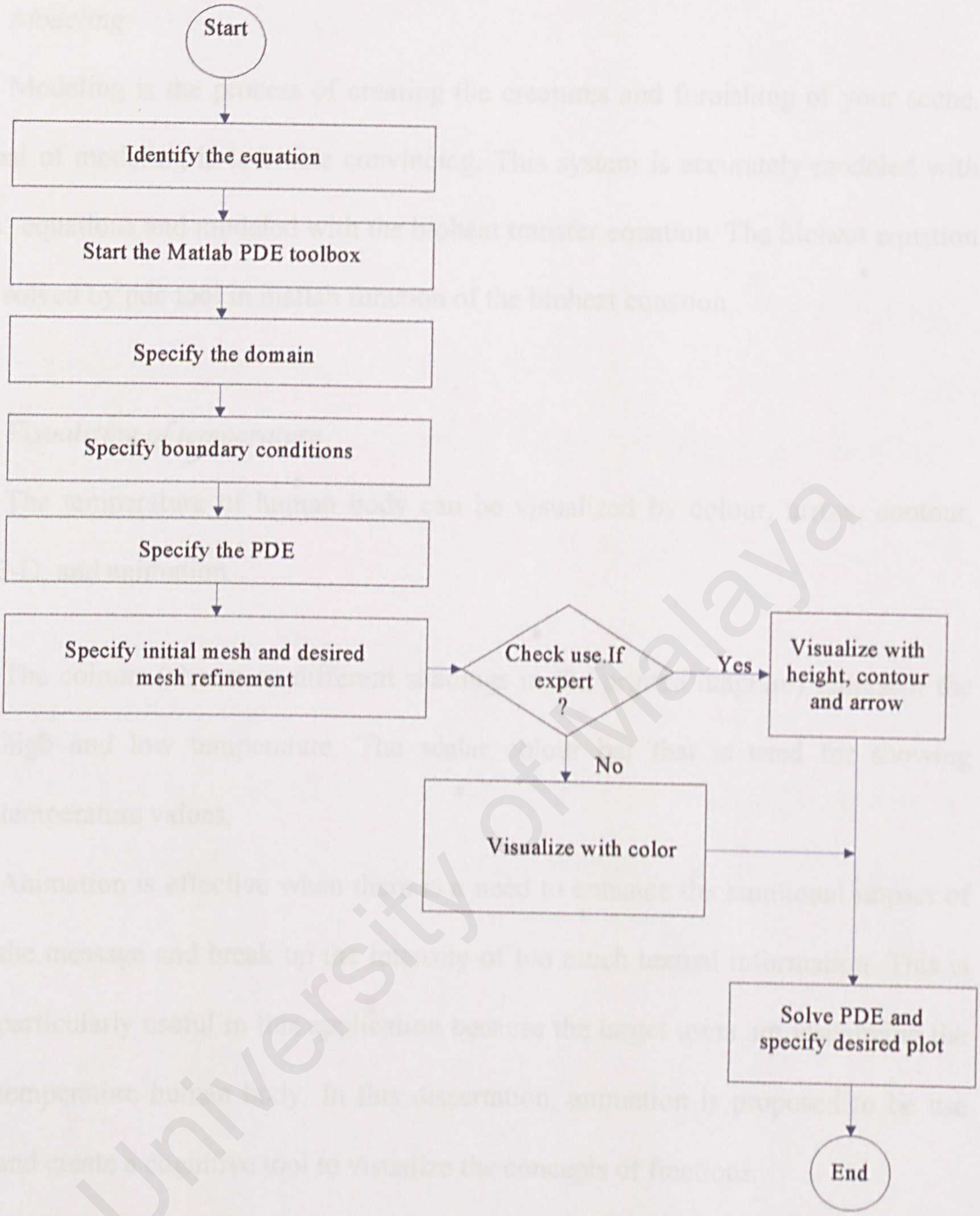


Figure 5.3: The flow diagrams of program how to solve the equation

5.2.2 *Modeling*

Modeling is the process of creating the creatures and furnishing of your scene. The goal of modeling is to create convincing. This system is accurately modeled with Pennes' equations and modeled with the bioheat transfer equation. The bioheat equation can be solved by pde tool in matlab function of the bioheat equation.

5.2.3 *Visualizing of temperature*

The temperature of human body can be visualized by colour, arrow, contour, height 3-D, and animation.

- The colours (shown as different shadings in the printed diagram) represent the high and low temperature. The scalar colour bar that is used for showing temperature values.
- Animation is effective when there is a need to enhance the emotional impact of the message and break up the intensity of too much textual information. This is particularly useful in this application because the target users are visualizing the temperature human body. In this dissertation, animation is proposed to be use and create a cognitive tool to visualize the concepts of fractions.

5.2.4 *Interpretation*

Interpretation is a step in which temperature are identified and labeled with meaningful terms such as "whole matter". This process can be performed interactively.

5.3 Graphical user interface (GUI)

Using the interactive Guide Editor in Matlab developed the GUI. Developing an interface in Matlab proved to be challenge to the author. The GUI development tools were found to be rather unstable, causing constant crashes, and non-user friendly. However, through the implementation of a GUI, the visualization system has been made user-friendly. The user non-expert can view the visualization through just the clicks of buttons and the visualization will be view.

The basic emphases on GUI are:

- Simple but attractive and easy to understand
- Ease of browsing
- Guidance provided. Name of buttons are clearly stated and understood.
- User friendly. Users will not face any problem when using the system.

A prototype of the system is prepare in figure 5.1 as below:

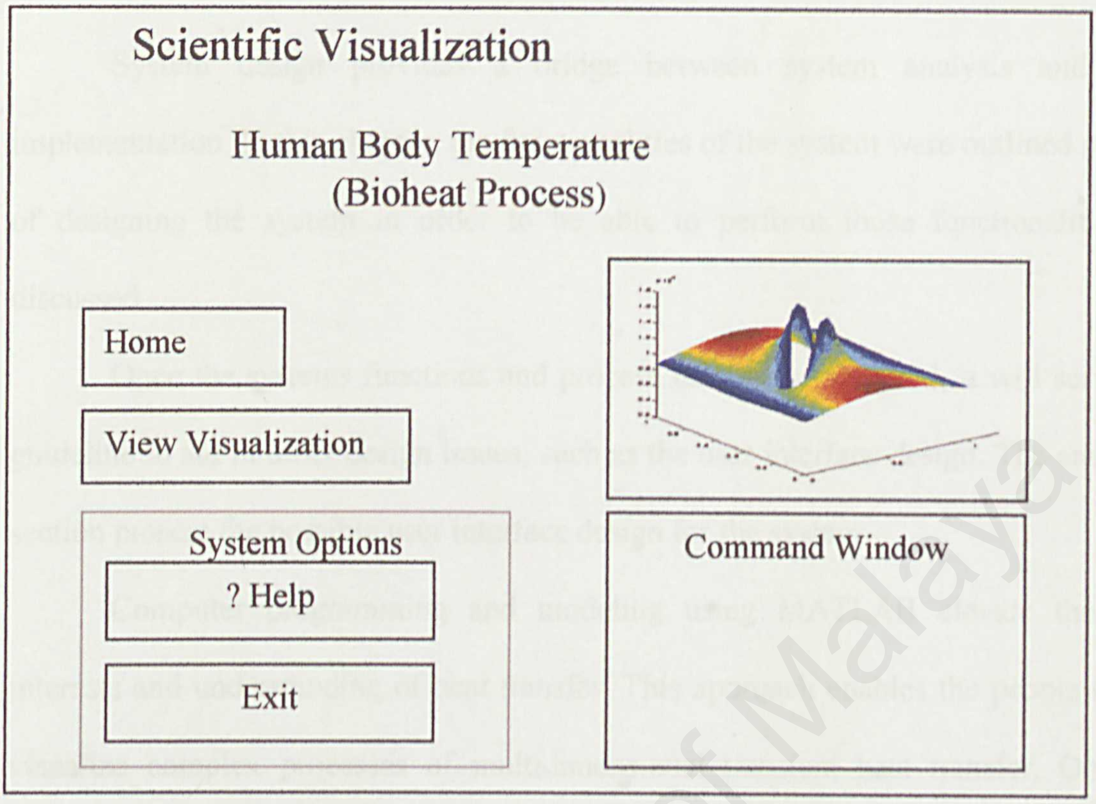


Figure 5.4: Interface design of scientific visualization of bioheat process

The prototype for this GUI will create in MATLAB using GUIDE, the GUI Development Environment.

5.4 Statement of Expected Outcome

This project is a system, which can visualize the temperature of human body and provide the information of the temperature. The expected outcomes of this project are:

- A system that will emphasis on user point of view.
- Interface that include multimedia application.
- Easy for enhancement and maintenance

5.5 Summary

System design provides a bridge between system analysis and system implementation. In this chapter, the functionalities of the system were outlined and ways of designing the system in order to be able to perform those functionalities were discussed.

Once the systems functions and process have been designed, it will served as a guideline to aid in other design issues, such as the user interface design. The ends of the section present the possible user interface design for the system

Computer programming and modeling using MATLAB elevate the people interests and understanding of heat transfer. This approach enables the people to better visualize complex processes of multidimensional transient heat transfer. Once they appreciate the graphical solutions of the pdetool GUI, they can then develop computer programs based on appropriate numerical techniques.

Chapter 6

System Implementation

CHAPTER 6: SYSTEM IMPLEMENTATION

6.1 Introduction

After the system-designing phase on how the system should be functioning, the next process will involve the implementation phase. The implementation phase is an important element especially when it involves a project developed where integration of system is needed between sub systems.

The design phase earlier in the system life is directed towards a final objective, which is to translate the concept of the system into a software representation that is understood by the computer. The coding process involves transforming of the design into a programming language.

The effort spent in this phase will actually determines the success of the system and ease the processes of modification, debugging, testing, verification, system integration and for future enhancement.

In this chapter, details regarding the steps of the implementation on the Scientific Visualization of Bioheat Process system will be discussed.

6.2 Development Environment

6.2.1 Hardware Used In Developing The System

The following hardware specifications have been used to develop this system:

i. Pentium (IV) 1.80 GHz processor
ii. 128MB DD RAM
iii. 20 GB Hard Disk
iv. Other standard computer peripherals

6.2.2 Software Used In Developing The System

The software tools used for system development are vital to the successful implementation of Scientific Visualization of Bioheat Process System. The software specifications used in the development of this project are illustrated in Table 5.1.

Table 6.1 Software Configurations.

Software	Usage	Description
Microsoft Windows 2000 or XP	System Requirement	Operating System
MATLAB 6.5	System Requirement	Application Developer
Adobe Photoshop 6.0	System Development	Graphics Editor

6.2.3 Operating System

As mentioned the platform or operating chosen for the development of Scientific Visualization of Bioheat Process System as the stand alone system is the Microsoft Windows XP or Windows 2000. The rationality behind the choosing of Windows XP or 2000 as the operating system is solely based on the performance as well as the reliability of the operating system architecture. These features eventually make the Windows XP or 2000 as the ideal operating system for most development of systems.

6.2.4 Programming Language Chosen

The language chosen for the development of Scientific Visualization of Bioheat Process System is MATLAB 6.5 which functions as the visualization system. The reason for me to choose this language is because of the simple structure and syntax of MATLAB 6.5 language makes it easier for me to identify and debug the system.

One of the important advantages of using MATLAB in visualization applications is the availability of built-in functions called toolboxes. In this work, the pdetool GUI is applied in solving transient heat transfer problem.

The pdetool GUI can be started by typing pdetool at MATLAB's command prompt as follows:

```
>>pdetool
```

To GUI can be start by typing guide at MATLAB's command prompt as follows:

```
>>guide
```

6.2.5 *System Coding*

Most of the time, this system is designed using MATLAB Programming.

Table 6.2 List of MATLAB function

MATLAB Function	Sub Function	Description
function varargout	a. function Main_OpeningFcn	The main page of this system
	b. function btnHome_Callback	The Home button
	c. function btnHelp_Callback	The Help button
	d. function close_pushbutton_Callback	The Close button
	e. function btnView_Callback	The View Visualization button
	f. function submit_Callback	Define the user
	g. function reset_Callback	To reset the user
function pdemodel	a. pderect	Geometry description - rectangle
	b. pdeellip	Geometry description - ellipse

	c. pdecirc	Geometry description - circle
	d. pdepoly	Geometry description - polygon
	e. pdesetbd	Set boundary conditions
	f. pdetool('initmesh')	Mesh generation
	g. pdeseteq	Set PDE coefficients
	h. pdetool('solve')	Solve PDE

6.3 Summary

To sum up chapter 6, we can say that the implementation of Scientific Visualization of Bioheat Process System focus on various aspects which governs the functionality of the system to fulfil the functional and non functional requirements of the system and also describes the function in MATLAB. Hence the choosing of development platform which ranges from the operating system till the programming platform chosen has to be up most suitable to the requirement of the system.

Chapter 7

System Testing

CHAPTER 7: SYSTEM TESTING

7.1 Introduction

System testing is essential to ensure the system performs according to its specifications and in line with users' requirements and expectations. Testing is done throughout system development, not just at the end.

Testing is performed to detect the existence of faults and then try to correct it. Therefore, a systematically test procedure is need to make sure the system is tested thoroughly and completely. There are several types of testing: unit testing, module testing, integration testing, system testing and acceptance testing.

7.2 The testing process

7.2.1 Unit Testing

Individual components are tested to ensure that stand-alone program fixes the bug without side effects. After a new component is developed, it is tested independently, without other system components. This is to assure that the component is able to work accurately and persistently. All function on each button is examine to ensure it perform the entitle output such as link to the right page, call the right function to execute, display the correct message according to the error and eliminates all the syntax faults occurred.

For example, function submit_Callback (hObject, eventdata, handles), this function has to find the right page according to the user.

As the expert user, is generating visualization based on the value, different variables have different value so that it has to test to verify its robustness. What I have found out that is at first I used the value, this will raise an error when the visualization has viewed. The result not precisely when this problem happened. So I have to do a table of value of variables.

In this aspect, program coding is reviewed by examining it line by line in order to reduce semantic errors during implementation of the program. The coding is compared to the original design of the program flow. As the result, the correctness of coding can be identified. When the logic and flow of the program were identified, the code is commented and it can be traced in the future. The code is also examined and debugged in order to identify any fault coding.

Table 7.1 Table of Value

Material	Conductivity $Wm^{-1}K^{-1}$ (κ)	Density (Kg m^{-3})* 10^{-3} (p)	Specific heat (kJ kg^{-1} K^{-1}) (Cp)	Temperature (T)	Time (t)	Qm (W/m3)
Skin	0.001	1.085	3.6 3.68 3.8	0	1-100 sec	0

Bio-heat equation

$\rho\, c\, T' - \mathrm{div}(k\, \mathrm{grad}(T)) = Q + h(Text - T)$

Parameter

ρ density of tissue

c specific heat of tissue

t time

T tissue temperature

κ thermal conductivity of tissue

Q body heating coefficient

Text external temperature

h conv. Heat transfer coeffient

The Scientific Visualization system is a system that contains a few modules that perform specific function and in each of the modules created, it contains some sub-functions or action command. Therefore, unit testing is conducted on each of the sub-function and finally to the module itself.

In unit testing, the following aspects are considered:

- Interface – tested to ensure that information properly flows into and out of the program unit under test. I have test all interface in the Scientific Visualization system to make sure that data can be passed from the previous page to the next page.
- Boundary conditions – tested to ensure that the module operates properly at boundaries of geometry.

In the development of Scientific Visualization of Bioheat Process System, unit testing was done after the development of each module and not the end of the development of the whole system. The object and MATLAB codes were thoroughly checked and tested to ensure that the functions and data were implemented properly as indicated in the design.

7.2.2 Module testing

Module testing will focused on each sub module in Scientific Visualization of Bioheat Process System. There are totally 11 sub modules, so testing was carried out to ensure that the codes under the sub module work accordingly when all units of code are integrated.

Each of the sub modules is tested with the specific functions that perform to see whether they really output the results or fulfill the design requirements. For example, the draw geometry sub modules are tested whether it can really generate the correct geometry. If the error is occurred from a particular sub module, the part of the sub module could be identified and unit testing is used to identify the errors. After that, all sub modules group into module to perform the testing.

Table 7.2 Testing Description for module in Scientific Visualization System

Module	**Sub Module**	**Testing Description**
Main Menu	Login	1. Displaying correct page according to the user.
	Help	1. Search using for options available
	Exit	1. Correctly show the page to close the system.
	Command Window	1. Displaying message reference for the user.

Visualization (For Expert User)	Geometry	1. Draw the geometry in human body in 2D grid. 2. The test can draw successfully with the formula.
	Boundary Mode	1. Specify boundary condition for this geometry (group of segment)
	Mesh Mode	1. The mesh can be further refined to increase the computation accuracy'.
	PDE Mode	1. All the fields are check to ensure that are fill in with correct data in variables.
	Solve PDE	1. Matlab will interpolate the temperature distribution solve the equation. 2. Set the initial condition
	Various Visualization	1. Display visualization 2D temperature profiles in colour, contour, etc.

Visualization (For Non-Expert User)	System Overview	1. Show the hands geometry as apart of human body and the layers of the hands.
	Mesh	1. Show the mesh to solve the problem
	View Visualization (View 1, View 2and View 3)	1. Show the visualization and comparison between temperatures in hands as a part of human body.
	Logout	1. To logout the user

7.2.3 Integration testing

When I have satisfied that individual component are working correctly and meet out objectives, I combine them into a working system. This integration is planned and coordinated so that when a failure occurs, I have some idea of what caused it. In addition, the order in which components are tested affects our choice of test cases and tools. Some components may be in the coding phase, other may be in the unit-testing phase, and still other collections of components may be tested together.

The purpose of integration testing is to test the integration of overall performance of the system. The criteria taken in accounts are:

- Interface integrity – interfaces are tested as each modules to check if there is any lost of data across interfaces.
- Functional validity – tests designed to uncover functional errors are conducted.
- Information content – tests designed to uncover errors associated with data structures are conducted.
- Performance – tests designed to verify performance bounds established during software design are conducted.

The system tests performed:

- Compatibility Testing

  This test was performed, and the interface functions according to the requirements. The accuracy of data retrieval was high, and the speed of data retrieval was acceptable.

7.2.4 System testing

As mentioned earlier above, the Scientific Visualization of Bioheat Process System actually consists of 2 main functionality options. The first is on the modules which reflect the 4 menu in the Scientific Visualization of Bioheat Process System. The other part of the Scientific Visualization of Bioheat Process System is on the visualization functionality which consist the main functionality of visualization in body temperature. This reporting functionality consists of the geometry the body, boundary mode, mesh mode, pde mode and solves pde. The focus of the testing phase will focus on the integration of both the functionality. This is to ensure that both functionality as well as all the modules is able to work as an integrated unit as well as being able to perform their particular task correctly.

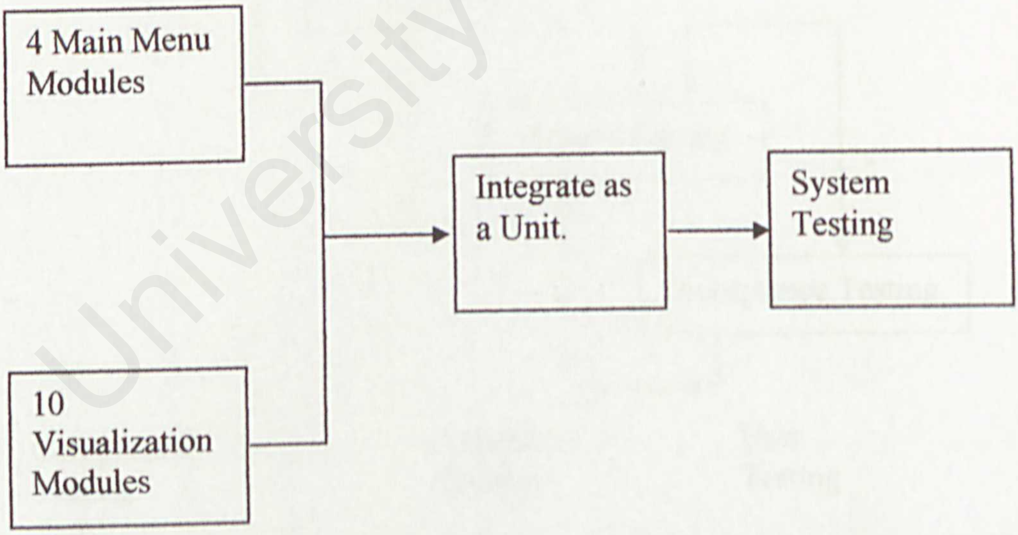


Figure 7.1 System Testing

7.2.5 Acceptance testing

Acceptance testing, or sometimes called as alpha testing is the final stage of testing whereby the system is tested before being accepted by the user for operational use. Acceptance testing reveals errors and omissions in the system requirements definition because the acceptance testing involves testing from the user. During the acceptance testing, the functionality of the system is demonstrated to the user and the users may experience the systems handle on.

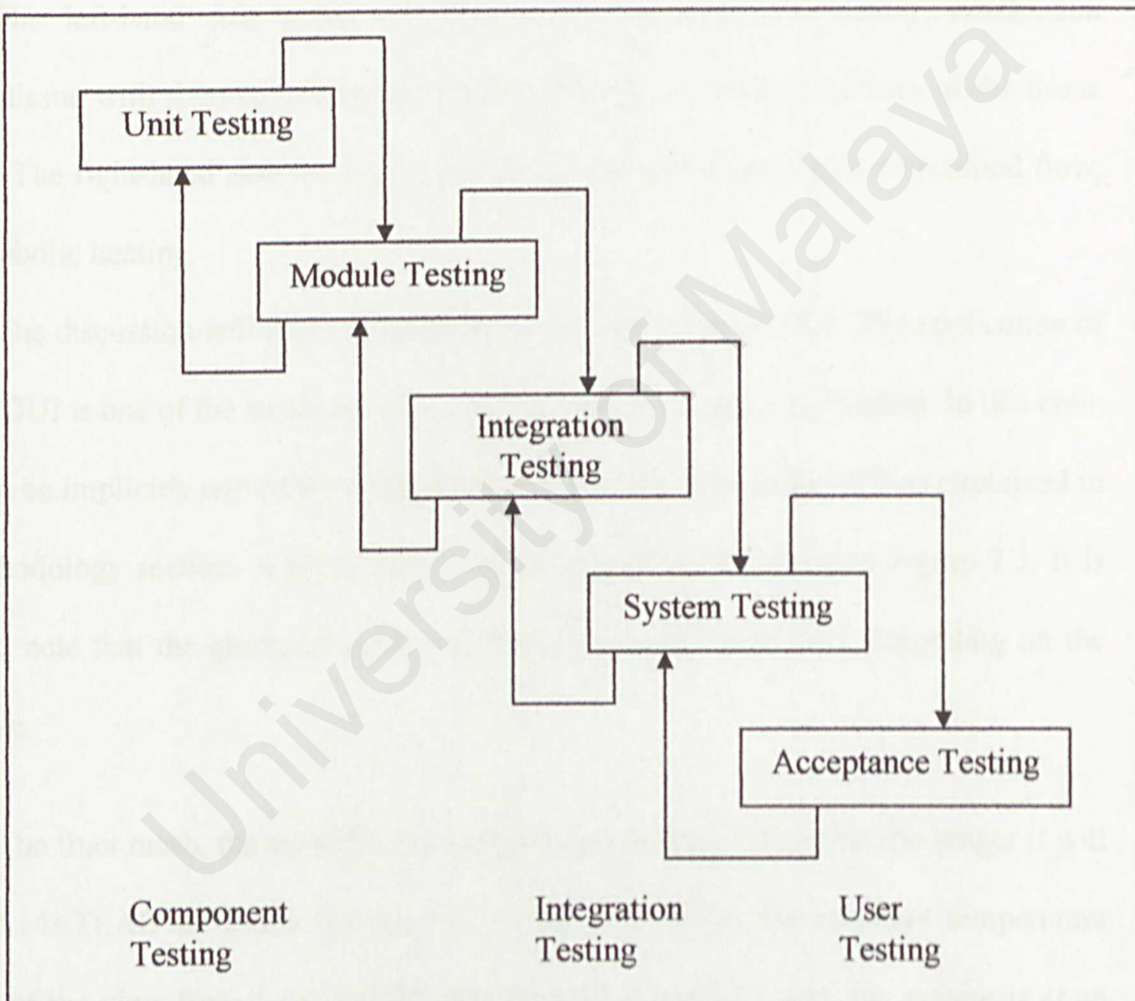


Figure 7.2: The testing stages

7.2 Results and discussion

Temperature predictions are commonly based on Pennes' bio-heat transfer equation (1) which is the conduction heat equation.

$\rho\, c\, T' - \mathrm{div}(\, k\, \mathrm{grad}(T)) = Q + h(Text - T)$ (1)

The left-hand side terms of equation (1) represent respectively, conduction through tissue with thermal conductivity kt and the rate of energy increase of the tissue volume. The right-hand side term describes heat convection associated with blood flow, and metabolic heating.

The discussion will focus on graphical outputs of pdetool GUI. The application of pdetool GUI is one of the easier ways to solve the equation and visualization. In this case, PDE can be implicitly solved by plugging in a few parameters in the GUI as explained in the methodology section. A set of pdetool GUI outputs is illustrated in Figure 7.3. It is worth to note that the graphical results of the pdetool GUI may vary depending on the mesh size.

The finer mesh, the smoother the temperature profiles will be but the longer it will take for MATLAB to obtain the solution. Figure 7.3 shows the resultant temperature profiles of the view from 1 sec to 100 sec duration. Initially (1 sec), the system is at an initial temperature of 37°C, which is the normal temperature of human body. After 25 seconds, the system temperature starts to increase heating and shows heating profiles. These temperature profiles vary according to the prescribed boundary condition specifications, of which temperatures are respectively set at 50°C, 100°C and 150°C. At the end of 100 sec simulation, almost all sectors of the hand are heated to temperature greater than 20 °C. The usefulness of pdetool GUI in the enhancement of heat transfer is indeed obvious.

Various parameters and factors may change while maintaining some other values. Geometry considers of confining boundaries is an important influencing factor in heat transfer. Different thickness very importance factor in heat transfer process. When thickness increases the burn is also increase quickly.

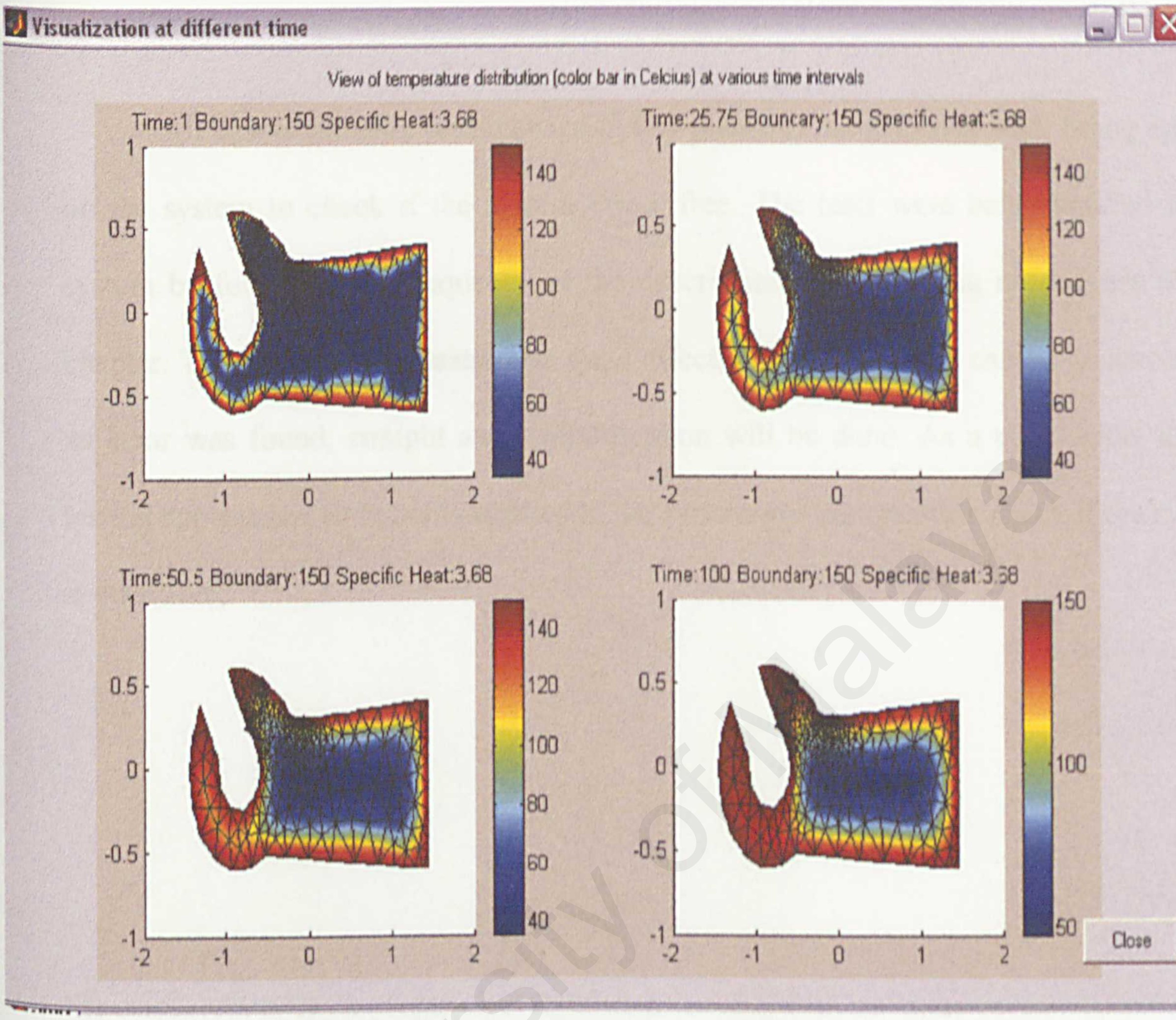


Figure 7.3 The resulting

7.4 Summary

All described tests were carried out as planned. All the tests were being applied on the system to check if the system errors free. The tests were being applied to the system by following the sequence of the description of the testing approaches in this chapter. The results of the tests were quite effective because errors can be uncovered. If an error was found, straight away modification will be done. As a conclusion, all the testing approaches were being applied to the system and successfully check if the system is error free.

Chapter 8

System Evaluation

CHAPTER 8: SYSTEM EVALUATION

8.1 Introduction

The final chapter for the thesis report of the Scientific Visualization of Bioheat Process module focuses on the system evaluation of the system as a functional visualization system. The evaluation of the system will eventually focus on the problems encountered during the development of the system, evaluation of the system by end user, system strength and limitations as well as its proposed enhancements.

8.2 System strengths

1. Visualization module is easy to use

   This system is ability to process on going data as well as performing geometry and visualization. The main strength of the Scientific Visualization of Bioheat Process System is the ability to perform the geometry in human body and its behaviors in visualization. Geometry representation of model elements is easy to understand.

2. User Friendly User Interface

   Has a simple interface design is the focus on one point which is simplicity. Since it is intended for the use of medical professional of an organization, it may seem ridiculous to 'decorate' the system as of the 'normal people' oriented system. The simple design is specially designed to suite a more professional look with a more simple background. The reason of simplicity is because to enable the user to make ease of use. This means that a simple interface will give the user more and faster understanding in using the system and they are able to use the system to the fullest potential. It also tries not to confuse the user with all different kind of decorations being 'crafted' on the interface.

8.3 System constraints

1. Lack of Functional Modules

   Although being able to perform the major and important task of the geometry and the visualization of temperature, this system only focus on one part in human body which is hands. Well this minor functionality may provide the ideas for the future enhancements of this system.

2. 2D Geometry

   At the present time, the PDE Toolbox solves only those 2-dimensional problems the extension to true 3-dimensional problem solving would require significant redesign of the toolbox. There is a product called FEMLAB that will solve true 3D problems but the problems, the software is difficult to get.

3. Security in Password

   Because the Matlab not have the function to visible the login name of expert user and non-expert user so, this system is not secure. To solve this problem I changed the background at login name into black so that, other people cannot see the password.

8.4 Future enhancement

1. Increase number of runs example

   It is would help to identify the important factors affecting temperature in human body.

2. More attractive interface

   Although the concept of the interface of Scientific Visualization of Bioheat Process System is on simplicity but there may be future enhancements whereby the creative minds of others may give some life into the interface.

3. Develop using other software

   This system did not include 3D geometry which can build using Java, FEMLAB, PRO-E and many more. This is partially due to lack of time, these software useful for future visualization especially in 3D geometry.

8.5 Problem encountered

1. Defining The System Scope Due To The Wide Area Of Study

   Most of the problems encountered under this category eventually occurred during the literature review period. Through research has to be conducted in order to understand how a normal Scientific Visualization of Bioheat Process System works. However the most challenging thought came from understanding how the visualization and the solving the partial differential equation flow. Since the principles of visualization disciplines seemed quite new and raw in my knowledge and understanding, therefore I find it quite hard to understand the visualization and their problem solving flows. However after further explanation by my supervisor, I eventually got a better understanding and able to relate them with the actual data flow in a computer system design and architecture.

2. Requirement Changes

   It is very difficult to develop and implement the system when the requirement changes very frequently. Sometimes it is easy to change the requirement, however, the coding need to be changed a lot in order to follow the new requirement.

3. No End User Evaluation

No end user tested the Scientific Visualization of Bioheat Process System because there is lack of time. Only Prof. Madya Dr. Roziati, my supervisor, tests on it and give some comments. So, I did not really know what the end user comment on my system is.

4. Integration Problems

There are several problems when the integration process. When integrating modules in the Scientific Visualization of Bioheat Process System, I find that there is problem in passing the value from one module to the other module because each module has a different function.

8.6 Knowledge Gained

Well for the past 4 months or so, things have been very interesting because I have been able to gain invaluable experience and knowledge while doing the Scientific Visualization of Bioheat Process System project. The knowledge and experience varies from programming, system analysis and design and other system development principles. I was able to apply the knowledge I learnt throughout my years in University Of Malaya into this project mainly on programming and system design principles.

Besides that, the knowledge gained from this project is the awareness of user's needs. It was found that users need a user-friendly environment, clear instructions and guidance. There are improvements in skills of finding information, classifying fields, solving problems and independently plan and accomplish the project on schedule without much supervision.

But the most important experience I have gained is the ability to work independently by myself, coordinating system design as well as integrating my final system. At the same time, the ability and experience to develop system is deemed very beneficial to me and I believe that these knowledge and experience I acquired during my time doing this project will sure prove its worth in the future especially when I approach the working world in the future.

8.7 Review on Goal

The project had successfully created a system that supported the information need for the organization to complete their functionality. Finally, it could be concluded that the objectives to establish the system had been achieved.

8.8 Summary

The Scientific Visualization of Bioheat Process System as a visualization model is fast, accurate and an excellent baseline visualizing the temperature of human body. It is very important for user to know well in their temperature. However, there are also some limitations that the system cannot be done. It needs to be enhanced in order to transform it to a more advance system. Despite the limitation, the project had reasonably achieved all its objectives.

This system is actually given the opportunity to integrate their theoretical knowledge in heat transfer numerical method and computing skills gained a priori. The system is modeled by applying heat balance across the hands human body. The resulting parabolic partial differential equation (PDE) is solved using finite difference method and PDE Toolbox (pdetool).

The advantages of visualizing the temperature in bio-heat process is that user can obtain view and visual effects. For example, in the future it can be helpful to doctor to detect the patient's symptoms because the system can give them views easy to see their temperature.

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Appendix

APPENDIX

Coding Used To Build The System

1. To pup up window while running in Matlab

```
function varargout = Main(varargin)


gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
               'gui_Singleton',  gui_Singleton, ...
               'gui_OpeningFcn', @Main_OpeningFcn, ...
               'gui_OutputFcn',  @Main_OutputFcn, ...
               'gui_LayoutFcn',  [] , ...
               'gui_Callback',   []);
if nargin & isstr(varargin{1})
   gui_State.gui_Callback = str2func(varargin{1});
end
if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
   gui_mainfcn(gui_State, varargin{:});
end
```

2. To check the user while login.

```
function submit_Callback(hObject, eventdata, handles)


user_name = get(handles.login,'String');
```

```
if strcmp(user_name,'expert')
    set(handles.login,'BackgroundColor','k');
    expert;
    set(handles.login,'String','');
elseif strcmp(user_name,'user')
    set(handles.login,'BackgroundColor','k');
    nonExpert;
    set(handles.login,'String','');
elseif ~strcmp(user_name,'expert') & ~strcmp(user_name,'user')
    warndlg('Incorrect Login Name ! Please enter a correct login name!','!! Error !!')
    set(handles.login,'BackgroundColor','k');
end
```

3. To reset the login.

```
function reset_Callback(hObject, eventdata, handles)

set(handles.login,'BackgroundColor','k');
set(handles.login, 'String', '')
```

4. To exit the system

```
function close_pushbutton_Callback(hObject, eventdata, handles)

pos_size = get(handles.FigureVisual,'Position');
user_response = modaldlg('Title','Confirm Close')
switch user_response
    case {'No'}
        %take no action
    case {'Yes'}
```

```
    %prepare to close
    delete (handles.FigureVisual)
end
```

5. **To use the visualization (pdetool)**

```
function [u3,u2,ux,uy]=rozy(asd,timerange,a,b,handles)

[pde_fig,ax]=pdeinit;
pdetool('appl_cb',9);
pdetool('snapon','on');
set(ax,'DataAspectRatio',[1 1 1]);
set(ax,'PlotBoxAspectRatio',[1.5 1 1]);
set(ax,'XLim',[-1.5 1.5]);
set(ax,'YLim',[-1 1]);
set(ax,'XTick',[ -1.5,...
 -1,...
 -0.5,...
 0,...
 0.5,...
 1,...
 1.5,...
]);
set(ax,'YTick',[ -1,...
 -0.5,...
 0,...
 0.5,...
 1,...
]);
```

```
pdetool('gridon','on');

% Geometry description:
pderect([-0.65000000000000013 1.45 0.29999999999999993 -
  0.49999999999999989],'R1');
pdeellip(-0.84999999999999998,0,0.59999999999999998,0.59999999999999998,...
0,'C2');
pdecirc(-0.84000000000000008,0,0.24990000000000004,'C1');
pdeellip(-
  0.13000000000000017,0.49999999999999994,0.20000000000000001,0.2000000000
  0000001,...
0,'C3');
pdepoly([ -0.7665063509461093,...
 -0.56650635094611002,...
 -0.13349364905389011,...
 -0.33349364905388934,...
],...
[ 0.20179491924311149,...
 0.54820508075688745,...
 0.29820508075688845,...
 -0.048205080756887508,...
],...
 'R2');
pderect([-0.24999999999999967 -0.05999999999999972 0.5
  0.29999999999999993],'R4');
pdepoly([ -1.3572245179455604,...
 -1.0295637002299638,...
 -0.74277548205444022,...
```

```
-1.070436299770037,...
],...
[ 0.44007272380203827,...
 0.66950329834245714,...
 0.25992727619796152,...
 0.030496701657542646,...
],...
 'R3');
pdepoly([ 0.049999999999999933,...
 1.45,...
 1.45,...
],...
[ 0.29999999999999993,...
 0.39999999999999991,...
 0.29999999999999993,...
],...
 'P1');
pdepoly([ -0.65000000000000002,...
 1.45,...
 1.45,...
],...
[ -0.5,...
 -0.59999999999999998,...
 -0.5,...
],...
 'P2');
set(findobj(get(pde_fig,'Children'),'Tag','PDEEval'),'String','(R1+C2+R2+R4)-
   (C1+R3+C3)+(P1+P2)')
```

```
% Boundary conditions:
pdetool('changemode',0)
pdetool('removeb',[3 7 8 9 12 13 14 15 16 18 22 24 25 26 27 28 29 30 38 39 40 41 ]);
pdesetbd(25,...
'dir',...
1,...
'1',...
'65')
pdesetbd(24,...
'dir',...
1,...
'1',...
'65')
pdesetbd(23,...
'dir',...
1,...
'1',...
'65')
pdesetbd(22,...
'dir',...
1,...
'1',...
'65')
pdesetbd(21,...
'dir',...
1,...
'1',...
```

```
'65')
pdesetbd(20,...
'dir',...
1,...
'1',...
'65')
pdesetbd(19,...
'dir',...
1,...
'1',...
'65')
pdesetbd(18,...
'dir',...
1,...
'1',...
'65')
pdesetbd(17,...
'dir',...
1,...
'1',...
'65')
pdesetbd(16,...
'dir',...
1,...
'1',...
'65')
pdesetbd(15,...
'dir',...
```

```
1,...
'1',...
'65')
pdesetbd(14,...
'dir',...
1,...
'1',...
'65')
pdesetbd(13,...
'dir',...
1,...
'1',...
'65')
pdesetbd(12,...
'dir',...
1,...
'1',...
'65')
pdesetbd(11,...
'dir',...
1,...
'1',...
'65')
pdesetbd(10,...
'dir',...
1,...
'1',...
'65')
```

```
pdesetbd(9,...
'dir',...
1,...
'1',...
'65')
pdesetbd(8,...
'dir',...
1,...
'1',...
'65')
pdesetbd(7,...
'dir',...
1,...
'1',...
'65')
pdesetbd(6,...
'dir',...
1,...
'1',...
'65')
pdesetbd(5,...
'dir',...
1,...
'1',...
'65')
pdesetbd(4,...
'dir',...
1,...
```

```
'1',...
'0')
pdesetbd(3,...
'dir',...
1,...
'1',...
'65')
pdesetbd(2,...
'dir',...
1,...
'1',...
'65')
pdesetbd(1,...
'dir',...
1,...
'1',...
'65')

% Mesh generation:
setuprop(pde_fig,'Hgrad',1.3);
setuprop(pde_fig,'refinemethod','regular');

% PDE coefficients:
pdeseteq(2,...
'0.001',...
'0',...
'(0)+(0).*(0.0)',...
'(1.085).*(3.68)',...
```

```
timerange,...
'36.5',...
'0.0',...
'[0 100]')
setuprop(pde_fig,'currparam',...
['1.085';...
'3.68 ';...
'0.001';...
'0    ';...
'0    ';...
'0.0  '])

% Solve parameters:
setuprop(pde_fig,'solveparam',...
str2mat('0','5118','10','pdeadworst',...
'0.5','longest','0','1E-4','','fixed','Inf'))

% Plotflags and user data strings:
setuprop(pde_fig,'plotflags',[1 1 1 1 1 1 1 1 0 0 0 51 1 0 0 0 0 1]);
setuprop(pde_fig,'colstring','');
setuprop(pde_fig,'arrowstring','');
setuprop(pde_fig,'deformstring','');
setuprop(pde_fig,'heightstring','');

% Solve PDE:
pdetool('solve')
u1=get(ax,'UserData');
u2=get(u1,'Cdata');
```

```
ux=get(u1,'Xdata');

uy=get(u1,'Ydata');

u3=min(u2(:));

figure(pde_fig);

clf reset

close
```

User Manual

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LIST OF FIGURE **Page**

CHAPTER 1: INTRODUCTION

1.1 Welcome

Welcome to Scientific Visualization of Bioheat Process in human body. This system is specially designed to computerize the management and visualizing process in temperature in human body. This system also is a user-friendly application, has meaningful icons and easy to use. All the system functions can be easily executed by a simple click.

1.2 About This Manual

This manual will introduce you to visualizing system and provide all information you need to use this system. This is the user manual that gives some simple instruction and guide for the user. This manual can helps users used the system more easily. Every function found in the system will be described in the manual. With using this manual, users will not get lost and will be able to use the system accurately.

Who Should Use This Manual

This manual will intended for the following categories of users:

- Department Physical (cancer specialist)
- Patient as a user

1.3 Introduction to the system

Scientific Visualization of Bioheat Process System is a system that is developed based on the visualization concept. This system consists of two modules that are Main Menu and Visualization. The mainly purpose of the visualization module is to help user to obtain view and visual effects and also in the future it can be helpful to doctor to detect the patient's symptoms because the system can give them views easy to see their temperature.

There are several sub modules in the Scientific Visualization of Bioheat Process system which are **login, help, and visualization for non-expert user and draw geometry, set boundary, and set the values in PDE specification and various visualization to expert user.** More details about those modules will be found in the following chapter.

CHAPTER 2: SYSTEM REQUIREMENT

In this chapter, the hardware requirement and also the software requirement used to implement the whole system have been listed. Users have to fulfill the minimum requirement before using the system. There are some minimum requirements before users can start using the system that is mean the user must install the software before use this system. The hardware and software requirement are listed as follow:

2.1 Hardware Requirement

- Pentium 4 1.8 GHz Processor or above
- 256 MB DDRAM or above
- 40 GHz Hard Disk or above

2.2 Software Requirement

- Any Microsoft Windows Operating System
- MATLAB 6.5

CHAPTER 3: GETTING STARTED

In chapter 3, steps have been listed to help users to start using the system. Users have to follow the steps stated in this chapter in order to start using the system. All this steps guide the users so that they will not get lost in using the system. There are several steps that are needed before starting using the Scientific Visualization of Bioheat Process. Those steps are listed as follow:

- Setup the system in your computer - copy from the cd into work, drive C at MATLAB program
- The main page of this system showed as follow:

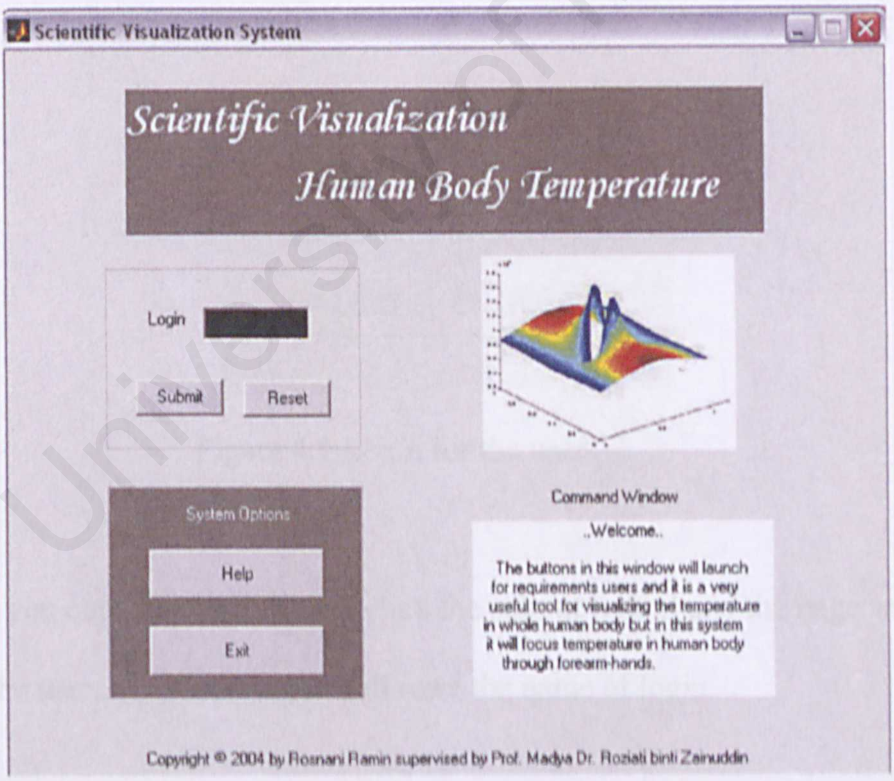

Figure 3.1 User Interface Design of Scientific Visualization of Bioheat Process System

CHAPTER 4: FUNCTION SECTION

In this chapter, the services found in the system will be illustrated. Every service with their particular interface will be listed to give users a clearly guide in using the system.

- Then you will come to the main page of the Scientific Visualization module as shown below.
- To choice the function that are needed, just click on the button in the left menu. There are several sub-functions inside each of the main services. When clicking on the button in the left menu, it will go to the module that you choose.
- Before you use this system you must get the login name from the expert user first.

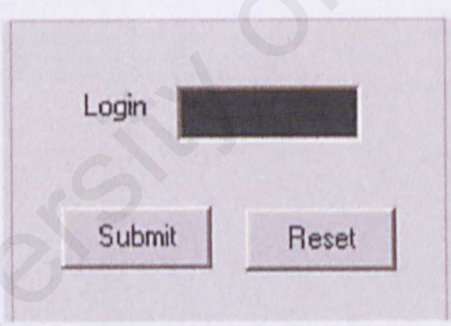

Figure 4.1 Login for the user

After you enter the login name, click the submit button and the page will display depends on the user. The reset button will reset the name of login.

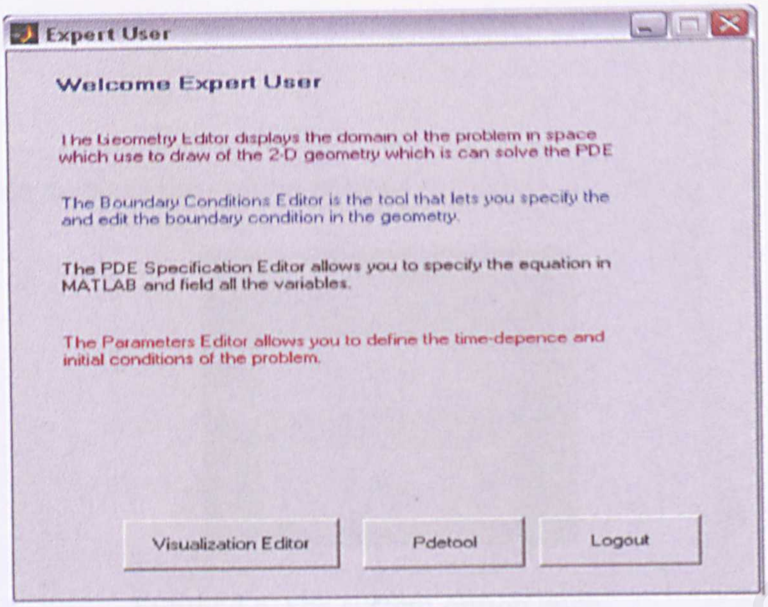

Figure 4.2 The expert user's page

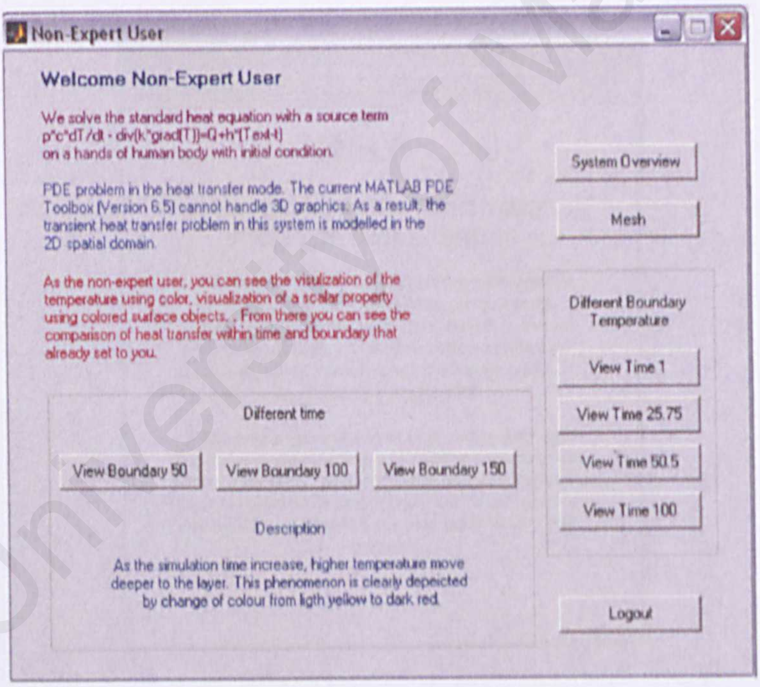

Figure 4.3 The non-expert user's page

➢ This module displays the system options.

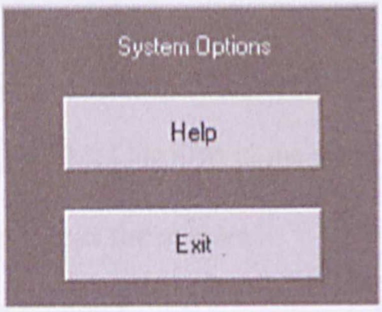

Figure 4.4 The system option page

❖ When you click the Help button this page will display

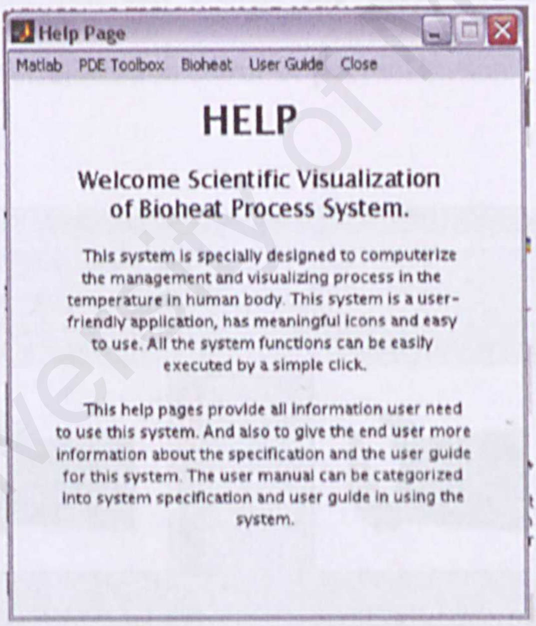

Figure 4.5 The help page

- There are four sub page to display information the different topic which are about MATLAB, PDE toolbox, Bioheat and User Guide.
- You can simply click on the topic to get the information.

❖ When you click the exit button this page will display:

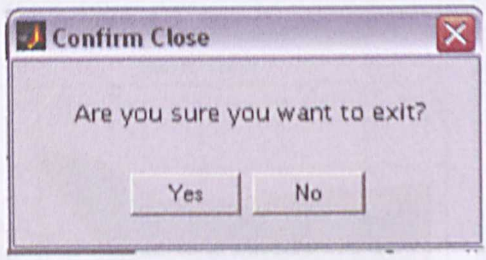

Figure 4.6 Confirm close page

- Click Yes to exit the system.
- Click No to cancel.

Expert User

As the expert user, you can change the geometry and then the value of parameters by click on the visualization editor or pdetool button.

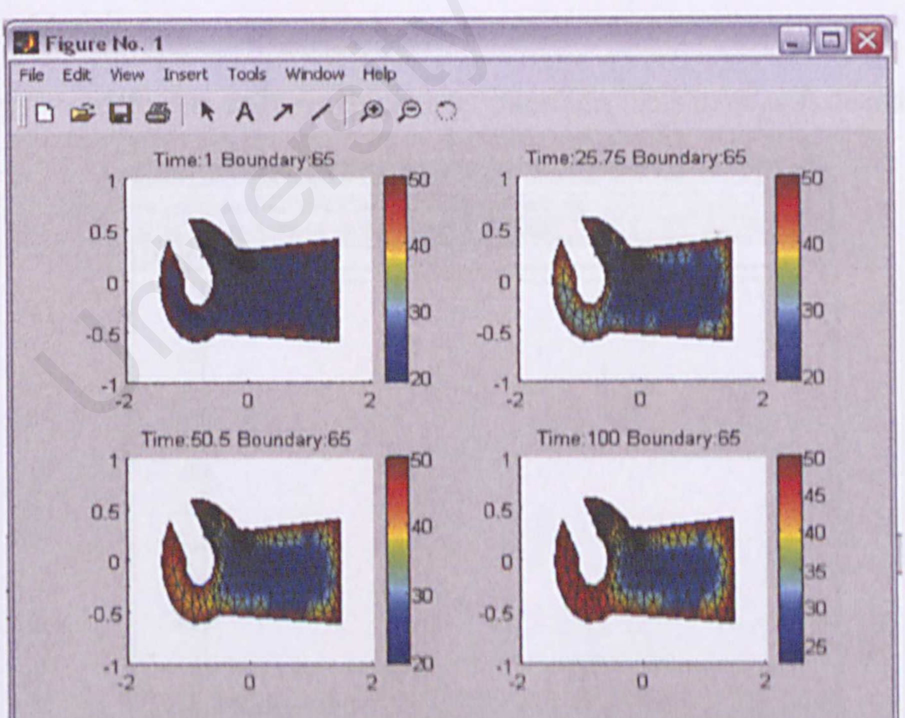

Figure 4.7 The final result

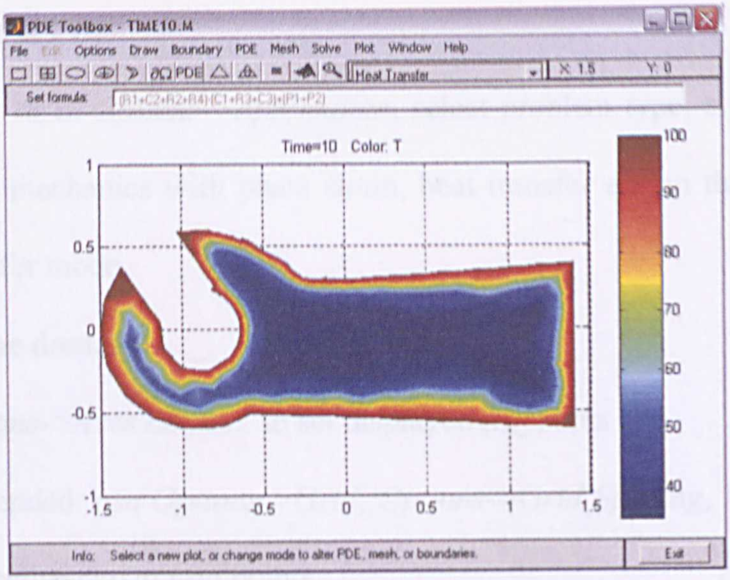

Figure 4.8 pdetool page

To start solve and change the 2D temperature profiles of the hands human body using pdetool GUI is describe as below:

First, start the Matlab PDE toolbox

- Start Matlab
- Type >> pdetool to start graphical user interface. This page will display:

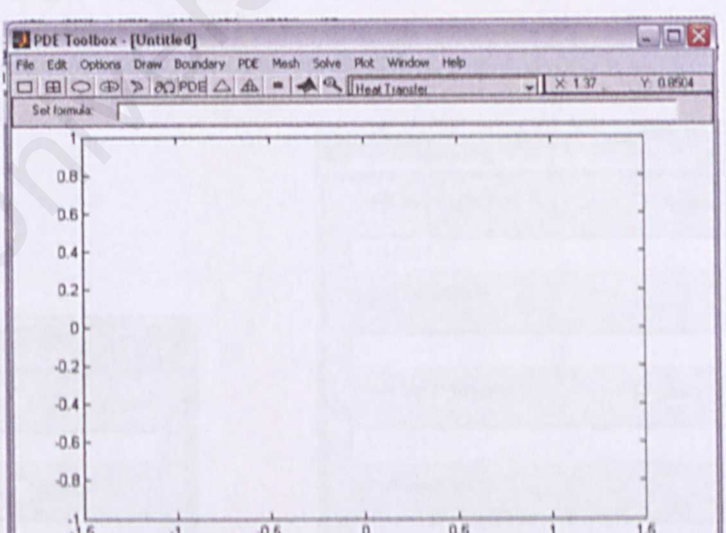

Figure 4.9 Default pdetool Enviroment

Second, specify the PDE

- In toolbar or in *Options->Application*, select problem type, e.g., generic scalar, structural mechanics with plane strain, heat transfer etc. in this system use the heat transfer mode.

Third, specify the domain

- Use *Options->Axes Limits...* to set displayed (x,y) area
- Recommended: use *Options->Grid*, *Options->Grid Spacing*, *Options->Snap* to automatically snap to grid points
- Draw primitives (rectangles, polygons, ellipses) from which to build up domain by addition/subtraction
    - Polygon: For each side, drag mouse with held left button from starting point to end point
    - Circle: click on the button with the ellipse with ``+", then drag the mouse with held *right* mouse button
- Above plotting area, type in formula how to combine primitives by addition/subtraction to form desired domain, e.g. C1-SQ1

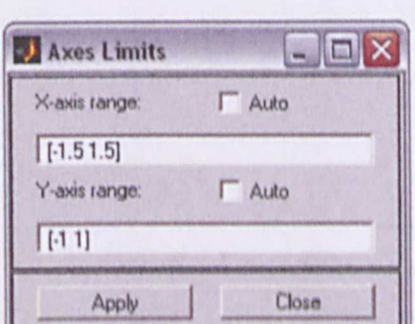

Figure 4.10 Axis Limit

Figure 4.11 Grid Spacing

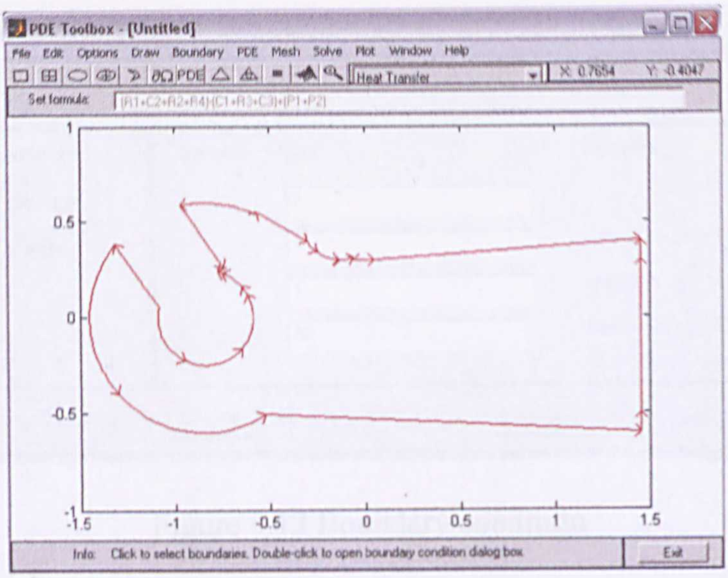

Figure 4.12 Draw Mode

Fourth, specify boundary conditions

- Enter boundary mode by clicking on ``d Omega" button or selecting *Boundary->Boundary Mode*
- select
    - one boundary segment by clicking on it
    - several boundary segments by Shift-clicking
    - all boundary segments by *Edit->Select All*,

  Then select *Boundary->Specify Boundary Condition* to specify boundary condition for this segment or group of segments

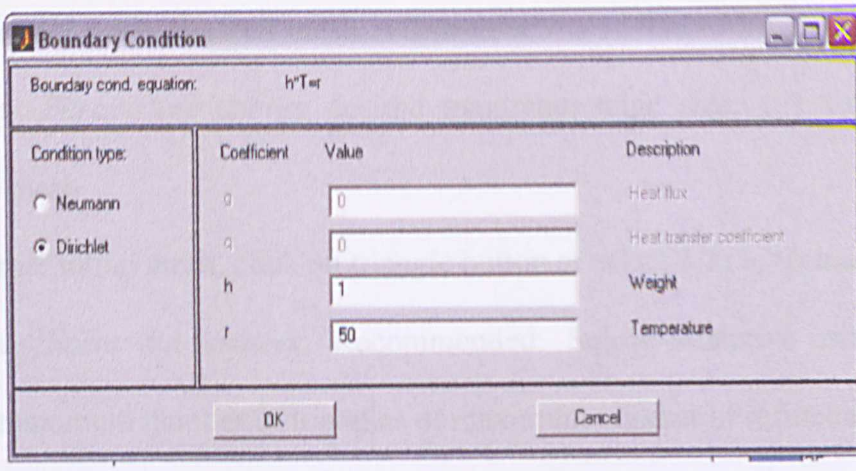

Figure 4.13 Boundary condition

Fifth, specify PDE specification

- In *PDE->PDE specification*:
    - Select Elliptic, Parabolic, Hyperbolic or Eigenmodes. For this situation, use the parabolic equation to solve.
    - Enter value in the field at PDE specification

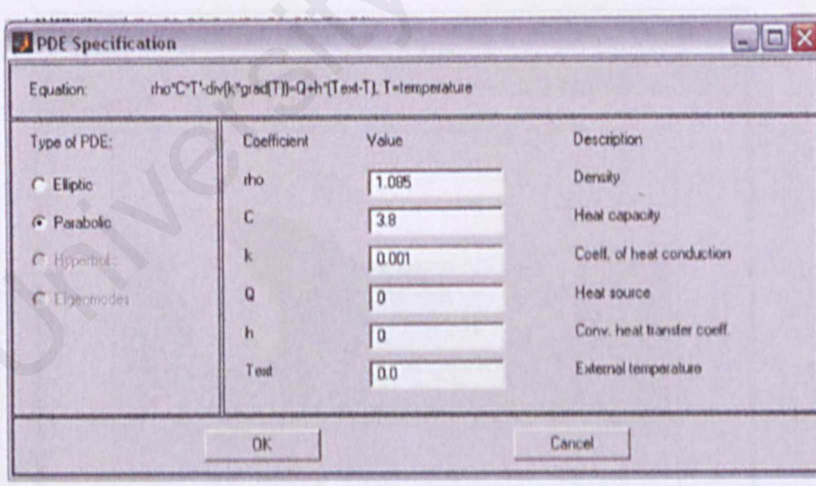

Figure 4.14 PDE Specification

Fifth, Specify initial mesh, desired mesh refinement

- In *Mesh->Parameters* choose desired maximum edge size, `Inf` for coarsest possible mesh
- To generate initial mesh, click on triangle button or select *Mesh->Initialize Mesh*
- In *Solve->Solve Parameters*: Recommended: Select Adaptive mode, enter desired maximum number of triangles or maximum number of refinement steps

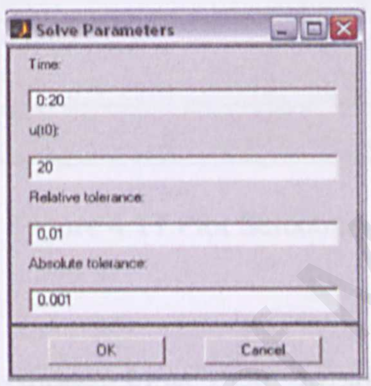

Figure 4.15 Solve Parameters

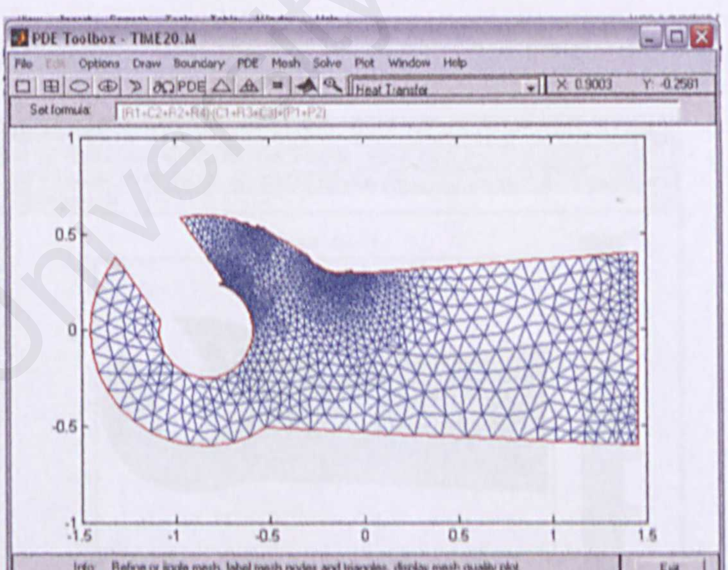

Figure 4.16 Mesh Initialization

Sixth, Specify desired plot

Click on Button with mesh surface or select *Plot->Parameters*. Recommended: Select *Show mesh*, *Colormap jet*

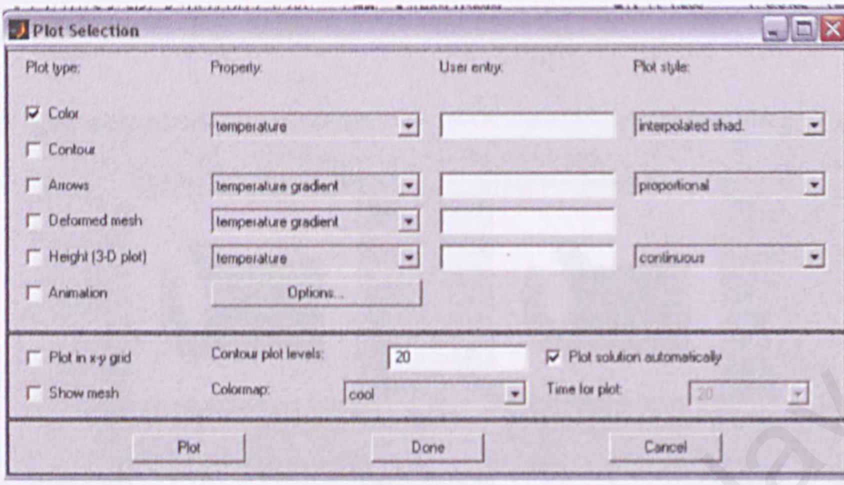

Figure 4.17 Plot Selection

Finally, Solve PDE

Push the ``='' button or select *Solve->Solve PDE*. In adaptive mode the number of triangles at each refinement step is shown in Matlab window. After the solution is found the specified plot is shown.

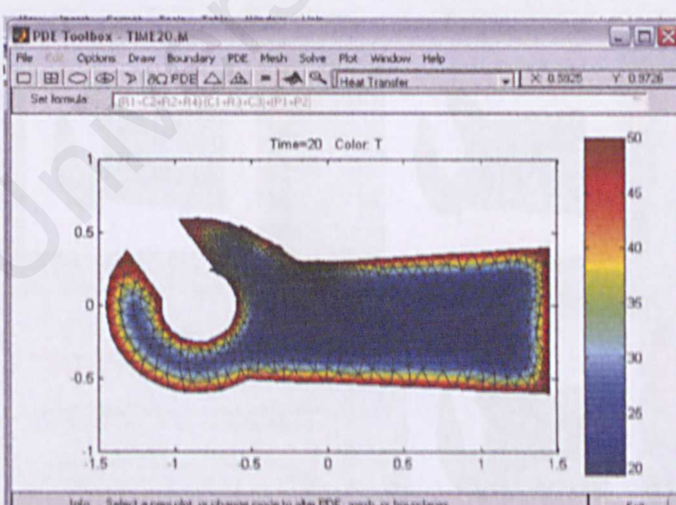

Figure 4.18 Final Solution (t= 20 sec)

Non-Expert User

As the non-expert user, you see the visualization when you click on the view visualization button and then, this page will display:

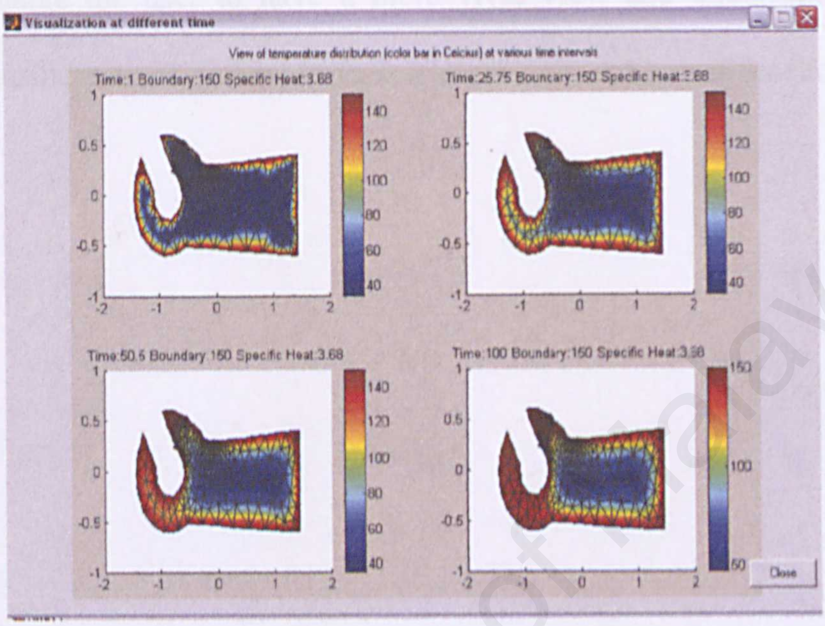

Figure 4.19 Result in different time

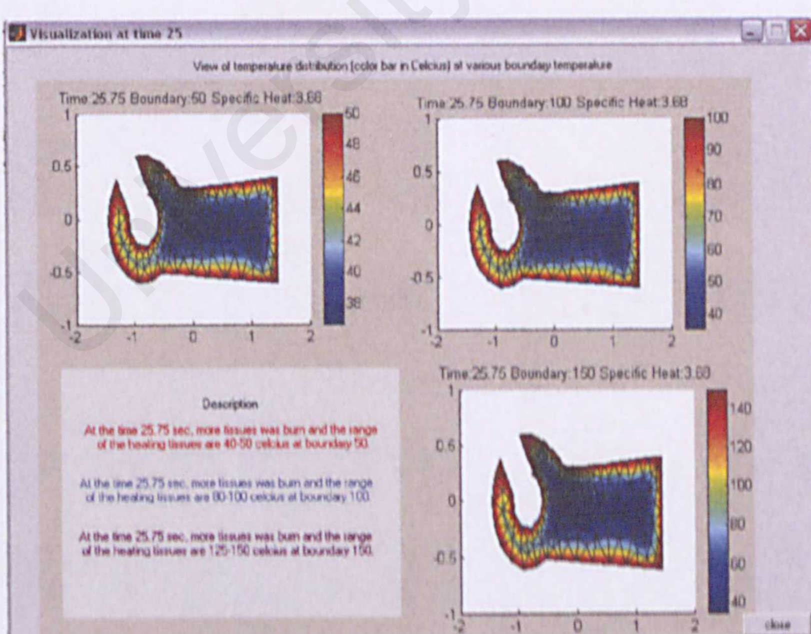

Figure 4.20 Result in different boundary temperature

CHAPTER 5: SUMMARY

The user manual focus like others is to provide the user the most ample knowledge which gives the most insights of the Scienntific Visualization and module. This is to enable the user to have a more vivid view and understanding what the Scientific Visualization of Bioheat Process System does and how it functions.