Chapter 1

BIOSENSORS AND AUTOMATED SYSTEMS FOR MEDICATION

The need of mankind today is ever increasing and it is necessary to support human life with reliable, affordable and sophisticated medical products. The advancements achieved in the fields of Electronics, Medical Signal Processing, Instrumentation and Automation have given us this hope and these have been made into reality through design and development of new devices that are considered as alternates. These devices support doctors and physicians by assisting and saving human life. Reliability and higher automation in medications have been achieved through miniaturization in devices. The modern needs to adhere to stricter and tougher regulatory norms have also ensured the medical fraternity to come out with alternatives. The need of the times is therefore in the design and development of automated drug delivery unit that would be beneficial to the common man. The ongoing discovery of newer forms of viruses in the human race that can result in changed life styles necessitates steps required to be taken as precaution for any untowardness that can affect human body. Modern day technology and future technologies need to be exploited for the benefit of human being. One of the areas in which the growth in technology can be fully utilized is the automated disease detection and drug delivery unit that
can automatically monitor, diagnose and also provide medication to human being without human intervention.

The life threatening diseases that destroy parts of human body are detected only when the patients reach the critical stage. Therefore, there exists a need to constantly monitor the parameters in human body and provide medication to cure diseases [1-3]. There are several diseases that can affect human body and therefore there must be means to accurately detect the diseases and subsequently classify them. Diseases classified, need to be treated by the selection of suitable drugs. Selection of drug and quantity of drug to be diffused is based on patient’s history, age, weight, height and other body conditions [4]. Drug selected based on all the parameters has to be diffused accurately with the use of an actuator. Drug diffusion needs to be controlled or monitored as it should not cause side effects. Thus the required drug to cure the identified disease should be targeted to specific locations. After the drug delivery, impact of drug on the disease detected and the causes of medication should be carefully monitored using sensors [5]. This is one of the major challenges in an automated process. This research work is an attempt towards design, modeling and analysis of an automated drug delivery unit that can be used to detect and deliver drug. The proposal is a miniaturized unit that can be used as a bio-chip. A biochip forms one of the prominent building blocks for automated drug delivery system.
1.1. **Principles of Biosensors and Disease Detection**

Oral and injection are the predominant methods of drug delivery. The limited means in drug delivery has impacted the progress of drug development [6]. Most drugs have been formulated to accommodate the oral or injection delivery routes, which are not always the most efficient routes for a particular therapy. New drugs such as proteins and nucleic acids require novel delivery technologies that can minimize side effects and lead to better patient compliance [7-9]. The business needs are also driving the need for new and effective drug delivery methods. Innovative drug delivery systems may make it possible to use certain chemical entities or biologics that were previously impractical because of toxicities and due to their difficulties in drug administration. For example, drug targeting is enabling the delivery of chemotherapy agents directly to tumors, reducing systemic side effects [10]. Research is continually on into investigating new ways to deliver macromolecules that facilitate the development of new biologic products such as bioblood proteins and biovaccines. Similarly, the success of DNA and RNA therapies will also depend on innovative drug delivery techniques [11-12]. The success of a drug is dependent on the delivery method. The efficiency of drug delivery to various parts of the body is directly affected by particle size. Nanostructure mediated drug delivery has the potential to enhance drug bioavailability, improve the timed release of drug molecules, and enable precision drug targeting. Nanoscale drug delivery systems can be implemented within pulmonary therapies, as gene delivery vectors,
and in stabilization of drug molecules that would otherwise degrade too rapidly [13-16]. Additional benefits of using targeted nanoscale drug carriers are reduced drug toxicity and more efficient drug distribution. Anatomic features such as the blood brain barrier, the branching pathways of the pulmonary system, and the tight epithelial junctions of the skin make it difficult for drugs to reach specific target locations. Nanostructured drug carriers will help to penetrate or overcome these barriers to drug delivery. The advantages of nanostructure-mediated drug delivery are their ability to deliver drug molecules directly into cells and the capacity to target tumors within healthy tissue. Nanostructured delivery architectures are promising candidates that will enable efficient and targeted delivery of novel drug compounds [17-20]. Sustained drug release and intracellular entry capability are the properties of nanoscale drug delivery mechanisms that minimize side effects and allow for the direct treatment of the cause of the disease rather than the symptoms of the disease.

1.2. Bio Sensors

A biosensor is an analytical device incorporating a biological material that can detect biological or chemical analytes in solution or in the atmosphere with a physiochemical transducer that produces discrete or continuous electrical signals proportional to the analytes. A biosensor consists of Bioreceptor and Transducer [21-31]. Figure 1.1 shows the working of a biosensor.
The bioreceptor is a biomolecule that recognizes the target analyte (ex: enzymes, antibodies, nucleic acids) and the transducers convert the recognition event into a measurable signal. Enzyme Electrode: Clark and Lyons designed the first biosensor in 1962.

**OUTPUT**

![Working of Biosensor](image)

**Figure 2.1. Working of Biosensor**

In this first enzyme electrode, an oxido-reductase enzyme, glucose oxidase, was held next to a platinum electrode in a membrane sandwich. The platinum anode polarized at + 0.6 V responded to the peroxide produced by the enzyme reaction with substrate. Biosensor technology couples our knowledge of biology with advances in microelectronics. A biosensor is composed of a biological component, such as a cell, enzyme or antibody, linked to a tiny transducer which is a device powered by one system that then supplies power (usually in another form) to a second system. Biosensors are detecting devices
that rely on the specificity of cells and molecules to identify and measure substances at extremely low concentrations. Biosensors can, for example [22, 24],

- measure the nutritional value, freshness and safety of food
- provide emergency room physicians with bedside measures of vital blood components
- locate and measure environmental pollutants
- detect and quantify explosives, toxins and biowarfare agents

### 1.2.1 Types of Transducers used in Biosensors

The following are the various types of transducers used in the biosensors [29-31]:

- **Conductimetric Transducer**: It detects changes in conductivity between two electrodes
- **Piezoelectric Transducer**: This transducer detects changes in mass
- **Thermal Transducer**: It measures changes in temperature
- **Amperometric Devices**: It detects changes in current. These devices measure currents generated when electrons are exchanged between a biological system and an electrode
- **Capacitive Transducer**: When the biorecognition reaction causes a change in the dielectric constant of the medium in the vicinity of the bioreceptor, capacitance measurement method can be used as a transducer
• **Optical Transducer**: Optical biosensors correlate changes in concentration, mass, or number of molecules to direct changes in the characteristics of light. For this method to work, one of the reactants or products of the biorecognition reaction has to be linked to colorimetric, fluorescent or luminescent indicator molecules. Usually, an optical fiber is used for guiding the light signals from the source to the detector. In the Intrinsic mode, the incident light passes through the sample and interacts directly with the sample.

1.2.2. Signal Transduction using Biosensors

The biosensors are designed for providing an electrical signal usually in micro or milli volts for a given analyte such as glucose [32-34]. Depending upon the characteristics of the analyte and its parameter, signal transduction is achieved. The parameters with which the signals are obtained are given in the following Table 1.1:

Table 1.1. Analytes and Biomaterials

<table>
<thead>
<tr>
<th>Some Common Biosensor Materials</th>
<th>Analytes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Gases</td>
<td>O₂, CO₂</td>
<td></td>
</tr>
<tr>
<td>Anesthetic Gases</td>
<td>N₂O, Halothane</td>
<td></td>
</tr>
<tr>
<td>Toxic Gases</td>
<td>H₂S, Cl₂, CO, NH₃</td>
<td></td>
</tr>
<tr>
<td>Flammable Gases</td>
<td>CH₄</td>
<td></td>
</tr>
<tr>
<td>Ions</td>
<td>H⁺, Li⁺, K⁺, Na⁺, Ca⁺, Phosphates, Heavy Metal Ions</td>
<td></td>
</tr>
<tr>
<td>Metabolites</td>
<td>Glucose, Urea</td>
<td></td>
</tr>
<tr>
<td>Trace Metabolites</td>
<td>Hormones, Steroids, Drugs</td>
<td></td>
</tr>
<tr>
<td>Toxic Vapors</td>
<td>Benzene, Toluene</td>
<td></td>
</tr>
<tr>
<td>Proteins and Nucleic Acids</td>
<td>DNA, RNA</td>
<td></td>
</tr>
<tr>
<td>Antigens and Antibodies</td>
<td>Human Ig, Anti-human Ig</td>
<td></td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Viruses, Bacteria, Parasites</td>
<td></td>
</tr>
</tbody>
</table>
Table 1.2. Biosensor Measurement Types and Applications [35-41]

<table>
<thead>
<tr>
<th>Transducer System</th>
<th>Measurement Mode</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion-Selective Electrode</td>
<td>Potentiometric</td>
<td>Ions in biological media, enzyme electrodes</td>
</tr>
<tr>
<td>Gas-Sensing Electrodes</td>
<td>Potentiometric</td>
<td>Gases, enzyme, organelle, cell or tissue electrodes</td>
</tr>
<tr>
<td>Field-Effect Transistors</td>
<td>Potentiometric</td>
<td>Ions, gases, enzyme substrates immunological analytes</td>
</tr>
<tr>
<td>Optoelectronic and Fiber-optic Devices</td>
<td>Optical</td>
<td>pH; enzymes; immunological analytes</td>
</tr>
<tr>
<td>Thermistors</td>
<td>Calorimetric</td>
<td>Enzyme, organelle, gases, pollutants, antibiotics, vitamins</td>
</tr>
<tr>
<td>Enzyme Electrodes</td>
<td>Amperometric</td>
<td>Enzymes, immunological systems</td>
</tr>
<tr>
<td>Conductimeter</td>
<td>Conductance</td>
<td>Enzyme substrates</td>
</tr>
<tr>
<td>Piezoelectric Crystals</td>
<td>Acoustic (mass)</td>
<td>Volatile gases and vapors, antibodies</td>
</tr>
</tbody>
</table>

Table 2.1 gives typical applications of different transducer systems. An example of detection process using an array of biosensors with necessary hardware and configurable modules is shown in the Figure 1.2. The array of biosensors samples high volume of signal collection which is concentrated for the purpose of extraction of purified signal detection. The signals are then conditioned for transduction so as to analyze data retrieval for decision making through display.
1.3. **Automated Drug Delivery System**

Automated disease detection and drug diffusion unit [42-46] shown in Figure 1.3 consists of a biosensor implanted on a human being. The sensors detect the presence of virus or micro-organism in a human body. The electrical signal generated by the sensor output is used to control a drug diffusion pump that automatically diffuses required quantity of drug to the patient.
Diseases in a human being are detected by the presence of sensors located at specific parts of the body. Sensors used within a human body interact with blood, tissues, DNAs and cells and detect the presence of specific antigen. Electrical signal generated by the sensor due to change in sensor property is measured and is used in detection of diseases. The detected disease is classified and is used in selection of a drug from the drug storage cell. Appropriate drug selected based on disease detected and other human body conditions are diffused through an actuator or pump. The drug diffused is monitored and is diffused in a controlled manner to cure the disease. Many researchers [45,46] have attempted in designing automated drug diffusion units and have been successful. However, there is a very limited or no research work reported giving a complete system development. Thus in this research work automated drug delivery unit with biosensors for disease detection, expert system based on neural network for disease classification and a PID control unit for drug delivery are integrated into a system to model automated drug delivery unit. This research work is an attempt in providing a feasible solution for disease detection and drug delivery unit. Figure 1.4 shows the block diagram of the proposed automated drug delivery system.
Multiple biosensors that can monitor one disease or multiple diseases are arranged in an array. Each sensor reacts to changes in biological conditions in a human being. The electrical signals generated by the sensors are captured and recorded. The expert system based on neural networks processes the stored data or the data captured using biosensors for classification. Disease classified is used in selection of drug and suitable drug is diffused in the body. A robust control unit or the controller logic monitors the sensor output, expert system output and controls the drug diffusion pump. The automated system consists of the following blocks:

- **Biosensors (Hardware)**
  - Disease sensing units with current/voltage output
- **Disease analyzer (Software)**
  - Data base consisting details of diseases and remedies
- **Master controller (Expert System - software)**
– Disease analyzer and control unit to diffuse the drug as
  per the disease

• Pump controller (Hardware)
  – Controls the drug diffusion based on the inputs provided
    by master controller

Biosensors are the most critical unit in the system; they need to be
accurate and durable. Sensitivity and specificity are the major
parameters that quantify biosensors. Biological changes need to be
detected and converted to electrical equivalent entity. Software
routines to classify diseases need to be robust and should clearly
distinguish between various diseases, nature of disease and intensity
of diseases. The expert system design should accurately classify the
signals detected and provide inputs to the control unit for drug
diffusion. The controller unit should diffuse the required drug in a
given time and need to monitor the diffusion process. The control unit
not only controls the on and off of the pump but also monitors the
diffusion action. A system that can perform the automated detection
and diffusion processes is of great use in biomedical application
domain.

1.4 Background for this Work

Population world over is rapidly increasing. Further due to global
warming and changes in human behaviour, mankind is prone to new
diseases and new viruses. The number of patients being scanned for
diseases is so large and providing treatment to all these patients is an expensive process and time consuming.

In general, diseases occurring are listed below:

- Allergy
- Autoimmune Diseases
- Cancer
- DNA, Paternity and Genetic disorders
- Environmental Toxin
- Fitness, Nutrition and Anti-Aging
- Gastrointestinal Diseases Revealed
- Heart Health
- Hormones and Metabolism
- Infectious Disease

Cancer constitutes one of the most dangerous diseases that has affected mankind and resulted in deaths of large number of people. Cancer care accounted for an estimated $104.1 billion in medical care expenditures in the United States in 2006 [47]. The coming years will see expenditures for cancer care increase at a faster rate than overall medical expenditure. As the population ages, the absolute number of people treated for cancer will increase faster than the overall population. Cancer prevalence will also increase relative to other disease categories even if cancer incidence rates remain constant or decrease. The costs are likely to increase as new, more advanced, and more expensive treatments are adopted as standards of care.
Expenditures associated with cancer are commonly reported by phase of care, which divides care into clinically relevant periods: (1) the initial phase, which is the period after diagnosis, (2) the last year of life, and (3) the continuing phase or the monitoring phase, which is the period between the initial phase and last year of life phase. Overall, approximately 33.6% of expenditures are in the initial phase, 36.8% in the continuing phase, and 29.6% in the last year of life phase of care. The percentage of all care represented by hospital care, either associated with cancer-directed surgery or other hospitalizations, varied for female breast (43%), colorectal (72%), lung (50%), and prostate cancers (33%)[47].

1.5 Indian Scenario in Healthcare

The Indian healthcare industry [48-50] is seen to be growing at a rapid pace and is expected to become a US $280 billion industry by 2020 [48]. The Indian healthcare market was estimated at US$35 billion in 2007 and is expected to reach over US $70 billion by 2012 and US $145 billion by 2017. According to the Investment Commission of India the healthcare sector has experienced phenomenal growth of 12 percent per annum in the last 4 years [49]. Rising income levels and a growing elderly population are all factors that are driving this growth. In addition, changing demographics, disease profiles and the shift from chronic to lifestyle diseases in the country has led to increased spending on healthcare delivery [50]. Even so, the vast majority of the country suffers from a poor standard
of healthcare infrastructure which has not kept up with the growing economy. Nearly one million Indians die every year due to inadequate healthcare facilities and 700 million people have no access to specialist care as 80% of specialists live in urban areas [50]. India in order to meet manpower shortages and reach world standards would require investments of up to $20 billion over the next 5 years [50]. Forty percent of the primary health centers in India are understaffed. According to WHO statistics, there are over 250 medical colleges in the Modern System of Medicine and over 400 in the Indian System of Medicine and Homeopathy (ISM&H). India produces over 250,000 doctors annually in the Modern System of Medicine and a similar number of ISM&H practitioners, nurses and para professionals [51]. Better policy regulations and the establishment of public private partnerships are the possible solutions to the problem of manpower shortage. India faces a huge need gap in terms of availability of number of hospital beds per 1000 population. With a world average of 3.96 hospital beds per 1000 population India stands just a little over 0.7 hospital beds per 1000 population. Moreover, India faces a shortage of doctors, nurses and paramedics that are needed to propel the growing healthcare industry. As incomes rise and the number of available financing options in terms of health insurance policies increase, consumers become more and more engaged in making informed decisions about their health and are well aware of the costs associated with those decisions. In order to remain competitive, healthcare providers are now not only looking at improving
operational efficiency but are also looking at ways of enhancing patient experience overall [52]. India suffers from high levels of disease including Malaria [17] and Tuberculosis where one third of the World’s tuberculosis cases are in India [53]. Ongoing Government of India education about HIV has led to decreases in the spread of HIV in recent years. The number of people living with AIDS in India is estimated to be between 2 and 3 million. However, in terms of the total population this is a small number. The country has had a sharp decrease in the estimated number of HIV infections; 2005 reports had claimed that there were 5.2 million to 5.7 million people affected with the virus. According to the World Health Organization 900,000 Indians die each year from drinking contaminated water and breathing in polluted air [54]. As India grapples with these basic issues, new challenges are emerging for example there is a rise in chronic adult diseases such as cardiovascular illnesses and diabetes as a consequence of changing lifestyles. On the other hand, among the men prostate cancer causes large amount of deaths and 4.6% of the patients suffering from cancer are found to be suffering from prostate cancer. Prostate cancer develops in the prostate gland in the male reproductive system. Many men are still uneducated. Further people due to financial and cultural reasons do not come forward to get diagnosed for prostate cancer. Prostate cancer is detected by detecting the presence of prostate specific antigen (PSA) in the blood [56-62].

Many of the diseases causing deaths and pain in human being can be detected at an early stage and medication can be administered
to cure the diseases. Once diagnosed and cured, it needs to be monitored at regular intervals so that the diseases do not reappear. The field of medicine and related domains has witnessed unparalleled technology breakthroughs leading to new and challenging discoveries. One of the areas in which large number of researchers has found a suitable technology is the automated drug delivery system that can detect, monitor and cure diseases in a human being.

1.6. Need for the Proposed Work

With the need for a sophisticated system such as automated drug delivery system that can be reliable and also be considered as an alternative to doctors during emergency, many researchers have proposed and developed technologies for automated drug system. In the Indian context, with vast population and varied set of diseases occurring among its people, there is a need for a low cost, reliable and sophisticated unit for disease detection and drug diffusion. The system consists of three major parts: Biosensors, Expert System and Drug Diffusion with Control Unit. In order to develop a prototype model of automated drug delivery unit that can be embedded in human body at specific location, the system should be miniaturized. Thus the systems should be very small and should perform its job as per the given specifications. In order to design, develop, model and simulate such a miniaturized model, there is a need to develop a mathematical model that mimics the actual system.
Currently, there are very few reports in literature reported on development of complete system or mathematical models for automated system. Biosensors necessary to detect diseases should be of nanometer size and nanotechnology is essential to develop such sensors. In India nanotechnology is still an emerging domain, and very few companies of Defense Organizations are developing or have expertise in nanotechnology related to biosensor development. For the development of automated system compounded by nonavailability of a biosensor, development of mathematical models is essential and they can be used to analyze the properties of biosensors. These can be used in disease detection. Thus there is a need for development of mathematical models for nanobio Sensors for disease detection and development of a prototype model based on the mathematical models to analyze the performances of the automated system. Secondly, the disease classification problem is one of the most challenging aspects of automated disease detection process. There is a need for a robust and reliable expert system that can automatically reconfigure its logic and accurately classify the diseases and also provide inputs to the control unit for drug delivery. Thirdly, the control unit needs to be very fast in its response and also monitor the drug delivery process. Along with these three major components required for automated disease detection and drug delivery system, there is a need for design and analysis of hardware and software models for biosensors, expert system and control unit.
1.7. Scope of the Work

This research work proposes a miniaturized nanotechnology based automated drug delivery unit based on biosensors for cancer detection. The mathematical models for biosensors, biosensor device simulations, embedded unit for decision making and drug delivery unit are modeled and analyzed for its performances and characteristics. Based on the developed models, a drug delivery unit is developed, software simulations of this unit is used for functional verification. The results obtained are validated with reference model. Biosensors that can detect presence of molecules that can be used in identifying cancer are mathematically modeled, simulated using standard nanodevice simulation tools. The results obtained are validated against standard reference. Designed biosensors are characterized for its performances for disease detection. New techniques for detecting multiple diseases based on the existing biosensors are being proposed, designed, modeled, and analyzed. Synthetic signals are modeled as equivalents to signals from biosensors, an embedded unit is designed to analyze these signals to find the disease and classify the diseases. Based on the disease classification, a control unit is activated to control the drug delivery unit as per the diseases detected. The work developed in this research, is a first towards automated drug delivery unit for multiple diseases.
1.8. Motivation

With the demand for doctors and medical practitioners to assist and support large human population becoming a challenge, it is essential to develop alternate means so that the human beings become less dependent on physicians. It is always better to avoid doctors and visits to hospitals for common diseases, and revisits to hospitals for medications in case of cancer and other chronic diseases. It is also essential to have a low cost, reliable, automated and sophisticated unit for medication and diagnosis. This work is motivated to meet the requirements of human needs with the advances in technology. With new devices becoming available in nanoelectronics domain, it is advantageous to use nanotechnology in medical applications. The initial literature review indicating nonavailability of mathematical models for nanobiosensor for system development was one of the major motivational factors in taking up this research work. Secondly, large numbers of people in India have limited accessibility to medical facilities. They also suffer from major diseases. It is therefore intended to develop a low cost product that can assist in this cause. This aspect also inspired the work. Thirdly, a reconfigurable system with a reliable expert system can be a prototype model to automated disease detection and drug delivery. Development of a hardware or software model for carrying out research work that can be in this domain, instead of analyzing the complete system in bits and pieces also inspired this work. This resulted in developing a
prototype model integrating nanobio sensors, expert system and control unit for automated disease detection and drug diffusion.

1.9. Assumptions

The research work is an interdisciplinary area comprising of Medical Signal Processing, Control System, Digital Design and Sensors. The following assumptions are made:

- Biosensors modeled in this work are tested using software test environment and it is assumed that the test environment is similar to a real time environment (suitable aspects of real time parameters are considered).
- Biosensor models developed are validated against available data sets that have been taken from reliable sources. It is assumed that the data available in the database are accurate and represent real time values.
- Expert system developed based on neural networks is trained using input and output parameters that are taken from standard database.
- It is assumed that such an actuator is available and is only required to develop a control unit to diffuse the drugs or control the actuator.
- A hardware model developed as a macro system is a prototype model for demonstration. It is assumed that the system can be scaled down to mimic the actual system at nanoscale level.
1.10. Thesis Overview

The research work carried out is organized and discussed in the following chapters:

**Chapter 2** presents background theory and literature review on automated disease detection and drug delivery system. Biosensors for disease detection are investigated, highlighting its major properties and characteristics. Various biosensors that have been reported in literature are reviewed; gaps in the literature are summarized. In this chapter a summary of automated system for disease detection and drug delivery is also discussed. The problem statement or problem definition for this research work is presented based on the literature review and the methods and methodology adopted mentioned.

**Chapter 3** presents a study report on various diseases that are very prominent in India, its causes, symptoms and test procedures. Diseases that are detected from blood samples and the parameters that are required to be detected are also presented. The basic property of biosensor and the performance factors for biosensors are also discussed in this chapter.

**Chapter 4** presents discussion on nanobio - sensors. In this chapter mathematical model for nanowire based biosensor is developed, modeled and simulated. The developed mathematical model is validated against real-time sensor parameters. The software models are developed using Matlab and Simulink. A test environment is developed to verify the models developed. FINFETs for biosensors are
modeled and analyzed for its performances. Results of the software model for biosensors and FINFETs are discussed in detail in this chapter; the models developed in this chapter are used in detection of diseases.

**Chapter 5** various diseases, its properties and detection principles are presented. Sensors developed in the Chapter 3 are used in chapter 5 and sensor arrays are developed to improve the performances of the biosensors for disease detection. New sensor array model are proposed to improve the sensitivity and specificity of the sensor developed. A novel approach for sensor array model is proposed and discussed in this chapter.

**Chapter 6** discusses the design and development of expert system based on neural networks for disease classification and detection. Modified neural network architecture for classification is presented in this work. The proposed system is used to classify ovarian cancer; classification efficiency is improved using the proposed model. FPGA implementation of the expert system is developed for hardware implementation. The developed system is reconfigurable, which is demonstrated in this chapter. Control unit for drug diffusion is designed and implemented on FPGA, a detailed discussion based on the obtained results are presented.

**Chapter 7** discusses the results of sensor, sensor array and modified sensor array for prostate cancer detection. Performances of expert system in classification and detection of ovarian cancer is presented.
FPGA implementation of expert system and PID controller is also presented in this chapter.

**Chapter 8** concludes this research work highlighting the major contributions, results obtained, design and implementation aspects. A detailed conclusion and scope for future work is presented in this chapter.

**Appendix – A** discusses design and development of a prototype model demonstrating automated drug delivery unit based on microcontrollers and peristaltic pump. In this chapter, various design parameters and design aspects required to develop a hardware model is presented. Results obtained based on the developed prototype model is discussed in detail.