AC 2011-601: A COURSE ON BIOMEDICAL INSTRUMENTATION UTILIZING LABORATORY BASED ON SYSTEM DESIGN APPROACH

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A Course on Biomedical Instrumentation Utilizing Laboratory Based on System Design Approach

Abstract

The paper explains how within the curriculum of an Electrical and Computer Engineering Technology program, the biomedical course is redesigned so that the students can follow the theory with laboratory experiments for processing biomedical signals utilizing System Design Approach (SDA). Isolated experiments focused on a single topic never conveyed the holistic feel that is gained through a complete instrumentation platform design.

This course is offered in the form of Learning Modules. The paper discuses the course system design learning modules which encompasses: 1) Bio signal, Transducers and Signal Conditioning, 2) Microcontrollers based Embedded System design, 3) Embedded System Programming, 4) Object-Oriented Programming (OOP) Design, 5) Use of Graphical User Interface (GUI), and 6) Final System Design Projects.

Biomedical System Design platform consists of a Microcontroller based system interfaced with a Personal Computer (PC). The Microcontroller based system will acquire a particular physiological signal. The microprocessor will perform digitization of the signal and capture the relevant data dedicatedly in real time basis. The data is further communicated to PC through a host of data communication protocols. The data is analyzed by a number of application programs designed by students. The students also design Graphical User Interface (GUI) application that operates on the stored data from the files and implements a number of operational parameters like alarms and physiological variables.

Redesigning of the course with this approach benefits the institution in establishing a laboratory without commercial instrumentation that is cost prohibitive. Commercial instrumentation utilizes proprietary technology that is not comprehendible and not amenable to student's learning. SDA provides a unique opportunity for the students, to learn instrument design and development in the biomedical area from concept to completion and will provide a lifelong learning experience that prepares them for their professional life.

Introduction

Traditionally a course in Biomedical Instrumentation is taught with either 1) theory alone or, 2) theory in conjunction with laboratory equipped with commercial instrumentations or, 3) theory with internship in a hospital environment. There are distinct advantages and some disadvantages in each of these approaches. A course based on theory alone, does not provides the students with practical feel of working with instruments.

An approach of theory with a dedicated laboratory has major disadvantages, 1) the initial cost of establishing a laboratory with commercial instrumentation 2) availability of a dedicated lab space and 3) the obsolesce of commercial instrumentation in a short span of time. An approach of theory with hospital internship does expose the student to real instrumentation and is desirable, but it is difficult to implement due to legal and other ramification.

The approach described in this paper addresses some of the above described disadvantages. In our approach the authors tries to provide the students the unique feel for the instrumentation design and thereby prepare them to perform as a designer, user and trouble shooter. The students with this background will have a better marketability in terms of job functionality. The authors have over a decade of successful experience in delivering interactive course delivery that has translated into better students' learning.

This SDA approach described here builds upon the strengths of students which they have gained in the earlier courses of 1) Electronics Systems, 2) Embedded Microcontroller design and 3) C^{++} Programming. In that respect the course integrate the knowledge content of these earlier courses. "Introduction to Biomedical Instrumentation" servers as an Instrumentation System design course. The course utilizes Biomedical System Design platform which consists of a microcontroller based system interfaced with a Personal Computer (PC) (Figure 1).

Course Audience and Format

The course is designed and is being offered as an introductory course in Biomedical Instrumentation. It is aimed at providing students interested in Medical Electronics Applications. This course is offered on a semester basis consisting of 16 weeks. The course has 2 hours of lecture and 3 hours of laboratory per week and has 3 credit hours allocated at its completion. The course could also be offered as a Seminar course that would have these two components: 1) Lecture part will be offered in a Distance Learning mode and 2) Laboratory portion of the course will be completed on an open lab basis.

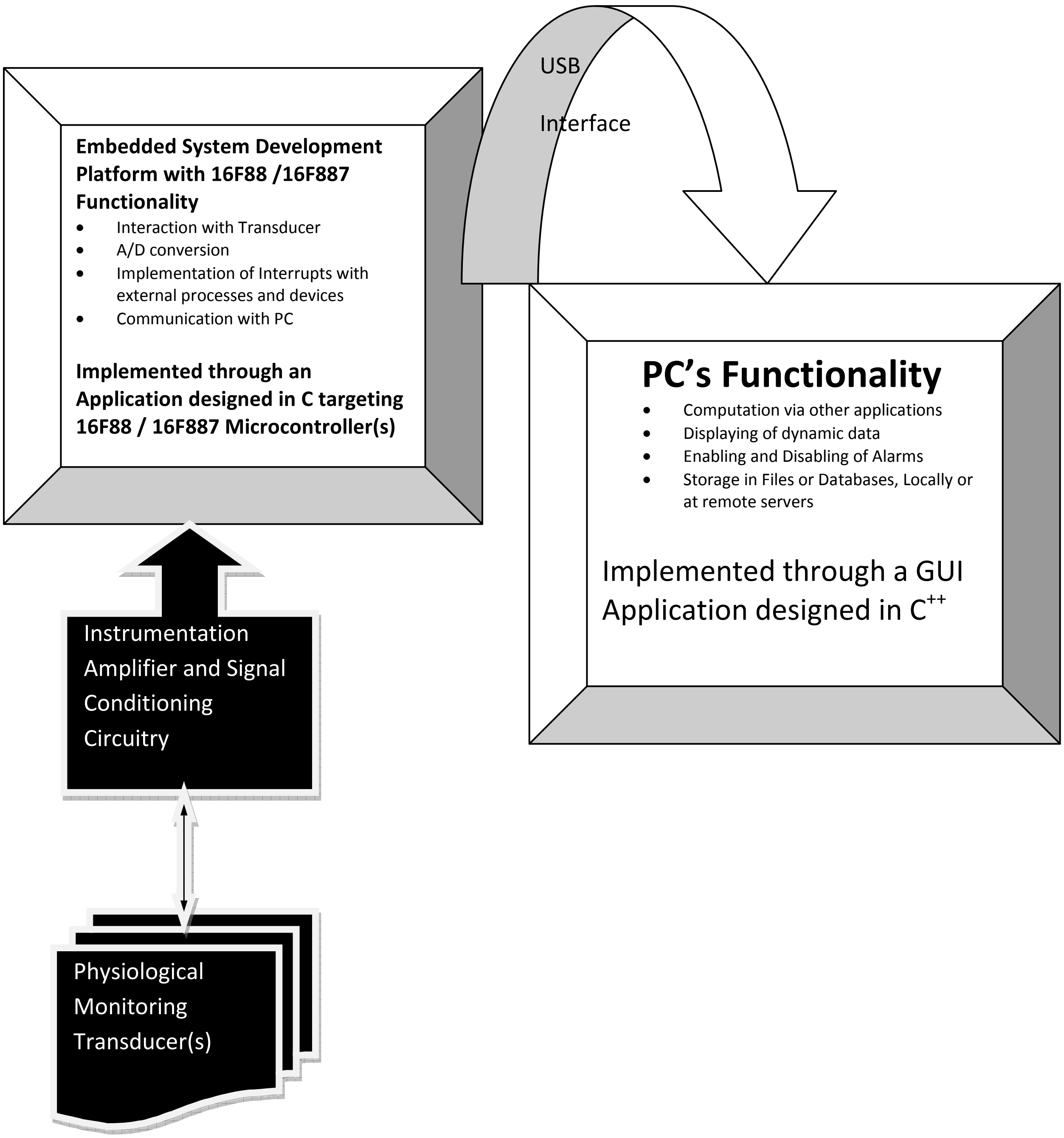

Figure 1 Biomedical System Design platform

Course Learning Modules

The primary motive of the technology students who enroll in this elective course is to make a career in a medical center or with a manufacturer of medical instrumentation. The primary job functions in a medical center would involve incoming inspection, calibration and periodic maintenance of medical instruments used in diagnosis/treatment. In the manufacturing area the job functions would include testing, marketing, sales, prototyping, field installation and service. Very few technology students will be working in the basic product design area of medical instrumentation.

The education students receive includes knowledge in the origin of bio signals, their electrical properties, the extraction of the bio signals from the human body, processing the signal to obtain useful information for diagnosis/treatment. The extraction of signals involves a particular type of transducer, signal amplification and processing, analysis and visual display of the signal, storage of the information and patient related safety aspects. The student should also know the limitations associated in every stage that is described above. The authors have used the collaborative learning process in a number of courses with considerable student learning outcome success and opted to use that for this course.

The following are the course system design learning modules, which are described in Table 1, showing the time coverage with respect to theory and laboratory:

1) Bio signal, Transducers and Signal Conditioning,
2) Microcontrollers based Embedded System design,
3) Embedded System Programming,
4) Object-Oriented Programming (OOP) Design,
5) Use of Graphical User Interface (GUI) and
6) Final System Design Projects.

Table1. Learning Modules Time Coverage

Learning Modules	Lecture Hours	Laboratory Hours
Bio signal, Transducers and Signal Conditioning	**20**	**15*** *Some of the theory is also delivered in the labs.
Microcontrollers based Embedded System design	**0**	**6**
Embedded System Programming	**0**	**0**
Object-Oriented Programming (OOP)	**6**	**6**
Use of Graphical User Interface (GUI)	**6**	**6**
Final System Design Projects	**0**	**15**
Total Hours	**32**	**48**

1. Bio Signals, Transducers and Signal Conditioning

The authors adopted the "The Design process for medical instruments proposed by Webster[1,] a revised version from a book by R.C.S. Cobbold[2].

The students are divided into groups of two/three and assigned a biomedical variable that is used for diagnosis (e.g. ECG, temperature, Blood pressure etc). The student group will use the frame work shown Figure 2 starting at the Measurand and proceed to the various boxes with guidance from the instructor. A one/two page summary report on each topic is presented to the class for discussion and critique. This process of learning will lead into the implementation stage using microcontroller based embedded system design of a basic biomedical instrument system.

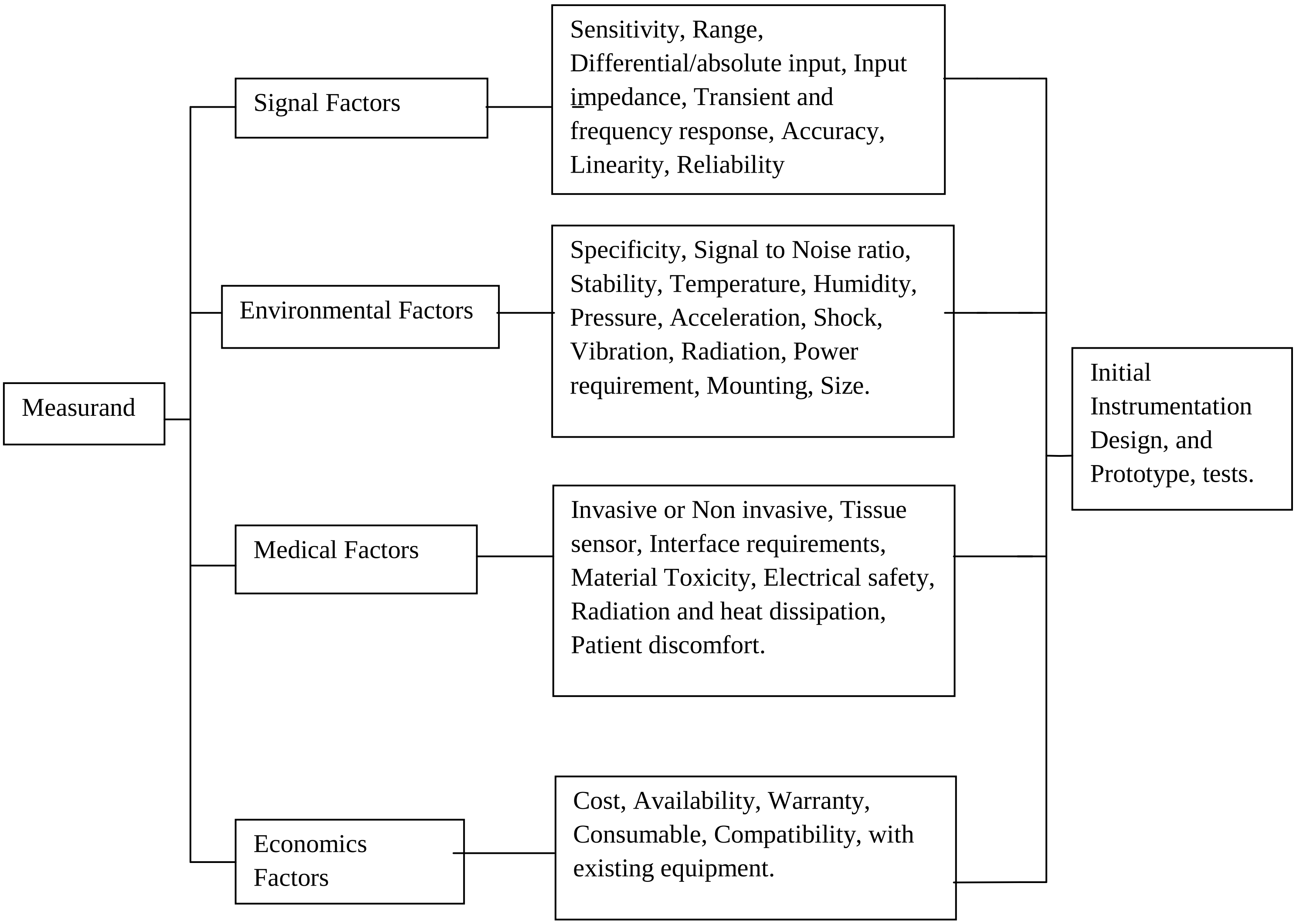

Figure 2 The Design process for medical instruments proposed by Webster[1]

2. Microcontroller(s) Based Embedded System Design

Through this Learning Module, students are able to capture the Bio-signal through the analog channel(s), digitize (A/D) the signal(s) and have the data ported to PC through the parallel or serial port(s) for further analysis, display and storage. The individual Microcontroller will have a dedicated monitoring and acquisition of signal through the utilization of its interrupts, timers and counters.

2.1 Embedded System Hardware Design and Development Tools

The authors have designed an in house hardware development platform[3] whose schematic is provided in Figure 3. The development board provides headers for accessing all the ports along with VDD and VSS. It has also a Serial port interface to access the PC and communicate via Rs232 port for down loading the program. By adding another serial port interface (not in the schematic), the development board could utilize the monitor display of PC as its extension. It has on board opto-isolators to protect the ports inputs and outputs. There are 2 seven segment displays, eight dip switches and eight toggle switches and eight LEDS for immediate interfacing.

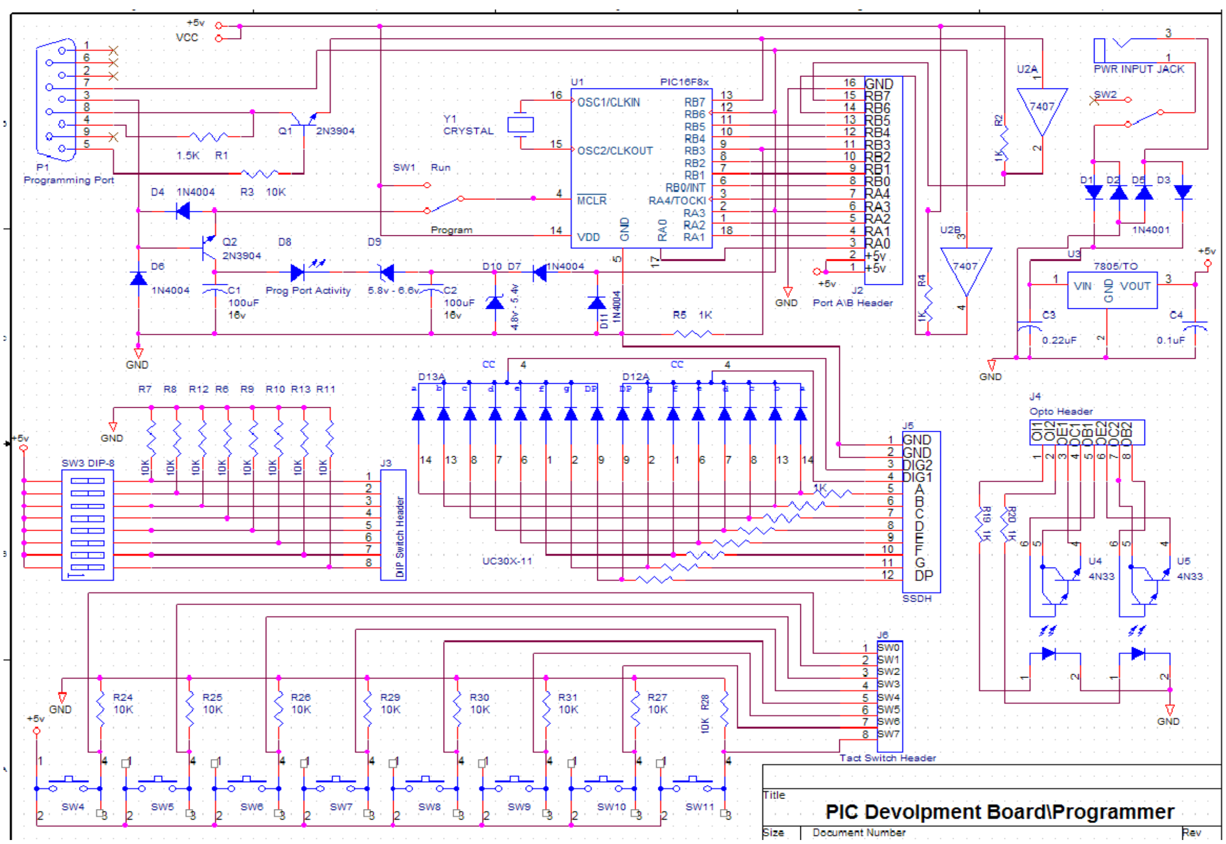

Figure 3 PIC 16F88 Design and Development Platform

3. Embedded System Programming

3.1 Embedded System Software Development Tools

This Learning Module utilizes C language for all the software development of 16F88 / 16F887 Microchip[4] microcontrollers. The compiler for the course that the authors utilized is Custom Computer Service's CCS v-4 C compiler. This could be invoked from the Microchip's MPLAB, the Integrated Development Environment (IDE) that is freely available from Microchip Technologies. The students could do the software development in MPLAB IDE and also could perform the simulation of the software as well. The other commercially available C Compilers are: 1) HI-Tech PICC v.9.50. 2) IAR Embedded Workbench v.2.21. 3) Forest Electronics C Compiler v.14. 4) B Knudsen CC5X and CC8E C Compiler and 5) Source boost C Compiler.

3.2 The Embedded System Hardware – Software Development Platform

The MPLAB IDE v7.61 by Microchip is the core development platform for the software. MPLAB is a freely down loadable from Microchip's Website. The MPLAB IDE provides an integrated development platform in which the students can do software development, which consist of an editor with all its functionality. The C compiler (in our case CCS v-4 C compiler) is invoked from within the MPLAB. After the compilation the MPLAB also provides a simulation mode that allows the simulation and testability of the code that allow us to monitor data, variables and all the Special Purpose Registers of the subject microcontroller. After satisfying with the simulation the next step is to down load the source code file which is the Standard Intel Hex Format. The PIC 16F88/16F887 Design and Development Platform (Figure 3) along with the respective interface circuitry which forms our respective Embedded System is connected to PC. The designed software file in the form of Standard Intel Hex Format is then down loaded using the WinPic, open source programmer which is again free download. Thus the whole development platform described here with the exception of the compiler is open architecture and utilizes open or free software.

4. Object-Oriented Programming (OOP) Design

Through this learning modules students learn the basics of OOP design, by realizing that a physical object could be emulated and created in the software and could possess all or some of the attributes that are of concern. Students learn that a physical organism exists and one of its physiological attributes being its body temperature, other being its pulse rate etc. A software based object of this organism can be created and its attributes can be manipulated and used.

5) Use of Graphical User Interface (GUI)

Through this learning module student learn 1) Computation via other applications, 2) Displaying of dynamic data, 3) Enabling and Disabling of Alarms and 4) Storage of data in Files or Databases, Locally or at remote servers. Students implement these functions through a GUI application designed in C^{++}.

Students learn to work with The USB data link that is established between the Microcontroller Embedded system design and PC can easily be achieved by USB-1024 by Measurement Computing[5]. The bus-powered USB-1024LS from Measurement Computing adds 24 channels of logic-level digital I/O to any USB port. It allows for monitoring and controlling the state of any simple electrical devices. The USB-1024LS is utilized as a DAQ device for the application. The combination of the USB-1024LS and Measurement Computing's DAQ software suite provides a complete data acquisition platform for taking measurements. The device is fully USB plug and play and easy to use. It is powered from the USB port, so no external power connection is required.

The GUI Application is designed using Embarcadero's C^{++} Builder XE[6] , which enables students to rapidly build native Windows applications using the C++ language and libraries. This allows the students to develop applications faster with pre-built components and drag-and-drop visual design.

6) Final System Design Projects

The course culminates in a Final Projects which are assessed based upon their comprehensiveness, originality and execution. Students are required to master the soft skills of comprehensive report writing on a weekly basis and of technical project report writing and project oral presentation based upon the Team's Final Project. Typically there are 3 to 4 separate final projects are performed in the semester depending upon the class size. These projects are openly shared among all the members of the class. The members of a team intensely work on their project and have gained intimate knowledge of their own project. The team members also further benefit and learn from other teams' projects. Thus the total knowledge base is shared with other teams of the class, thereby providing a platform for horizontal learning among the class members.

A Typical Project

Design a GUI application that would implement a "Sphygmomanometer" (Blood pressure measuring device for monitoring and measuring of arterial pressures). The application is to be implemented on PC under WINDOWS operating system.

The application is to acquire data using USB port from the transducers (in the lab a simulator is used). The application then display the 1) Systolic and 2) Diastolic pressure readings. The application analyzing the data would provide the user the particular classification shown in Table 2.

Table 2 Classification of blood pressure for adult's age 18 years and older[7]

Category	Systolic (mm Hg)		Diastolic (mm Hg)
Normal*	less than 120	and	less than 80
Pre-hypertension	120–139	or	80–89
Hypertension			
Stage 1	140–159	or	90–99
Stage 2	160 or higher	or	100 or higher

C^{++} Code for this Project

The following code that accomplishes the objective of the project is fairly straight forward, and is imbedded under the event handler Button1Click and is executed:

```
void __fastcall TForm1::Button1Click(TObject *Sender)
{

int x1 = 0 , y1 = 0;
            x1 =  (StrToInt(Edit1->Text));
             y1 =  (StrToInt(Edit2->Text));

if  ( x1 <120)
           {
  Edit3->Text = "Normal";
           }
if  ( (x1 >=120) && (x1 <=139 ))
           {
  Edit3->Text = "PreHypertension";
           }
if  ((x1 >=140) && (x1 <=159 ))
           {
  Edit3->Text = "Stage 1 Hypertension";
           }
if  ((x1 >=160) && (x1 <=179 ))
           {
  Edit3->Text = "Stage 2 Hypertension";
           }
if  ((x1 >= 180))
           {
  Edit3->Text = "Hpertension Crisis";
           }
```

```
            if  ( y1 <80)
            {
  Edit4->Text = "Normal";
            }

if  ( (y1 >= 80) && (y1 <=89 ))
            {
  Edit4->Text = "PreHypertension";
            }

if  ((y1 >=  90) && (y1 <= 99 ))
            {
  Edit4->Text = "Stage 1 Hypertension";
            }
if  ((y1 >=100) && (y1 <=109 ))
            {
  Edit4->Text = "Stage 2 Hypertension";
            }

if  ((y1 >= 110))
            {
  Edit4->Text = "Hpertension Crisis";
            }
}
```

The resulting screenshots are as follows (Figure 4, 5 and 6)

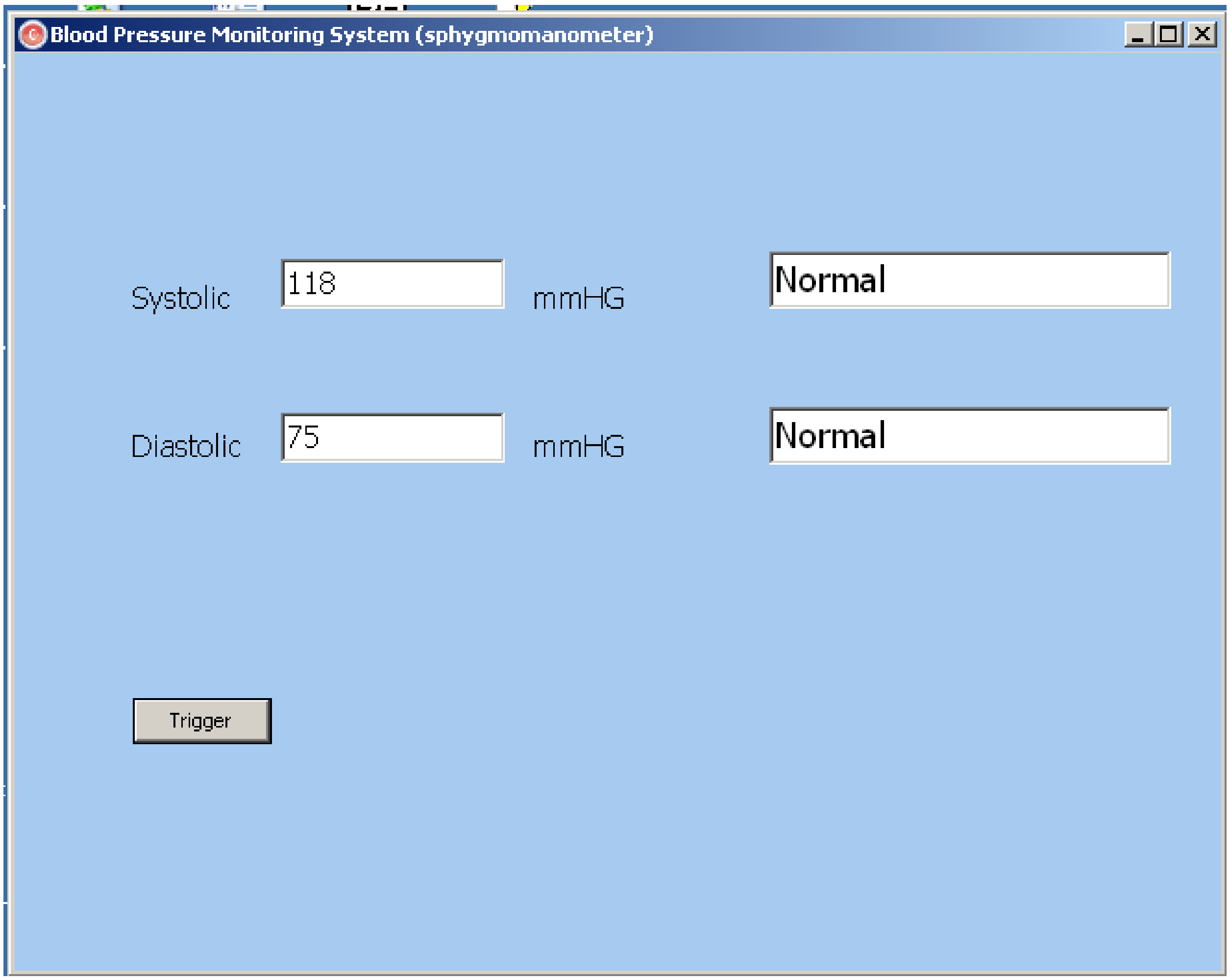

Figure 4 Blood Pressure Monitoring System (sphygmomanometer)
Case 1: Depicting Normal Hypertension Readings.

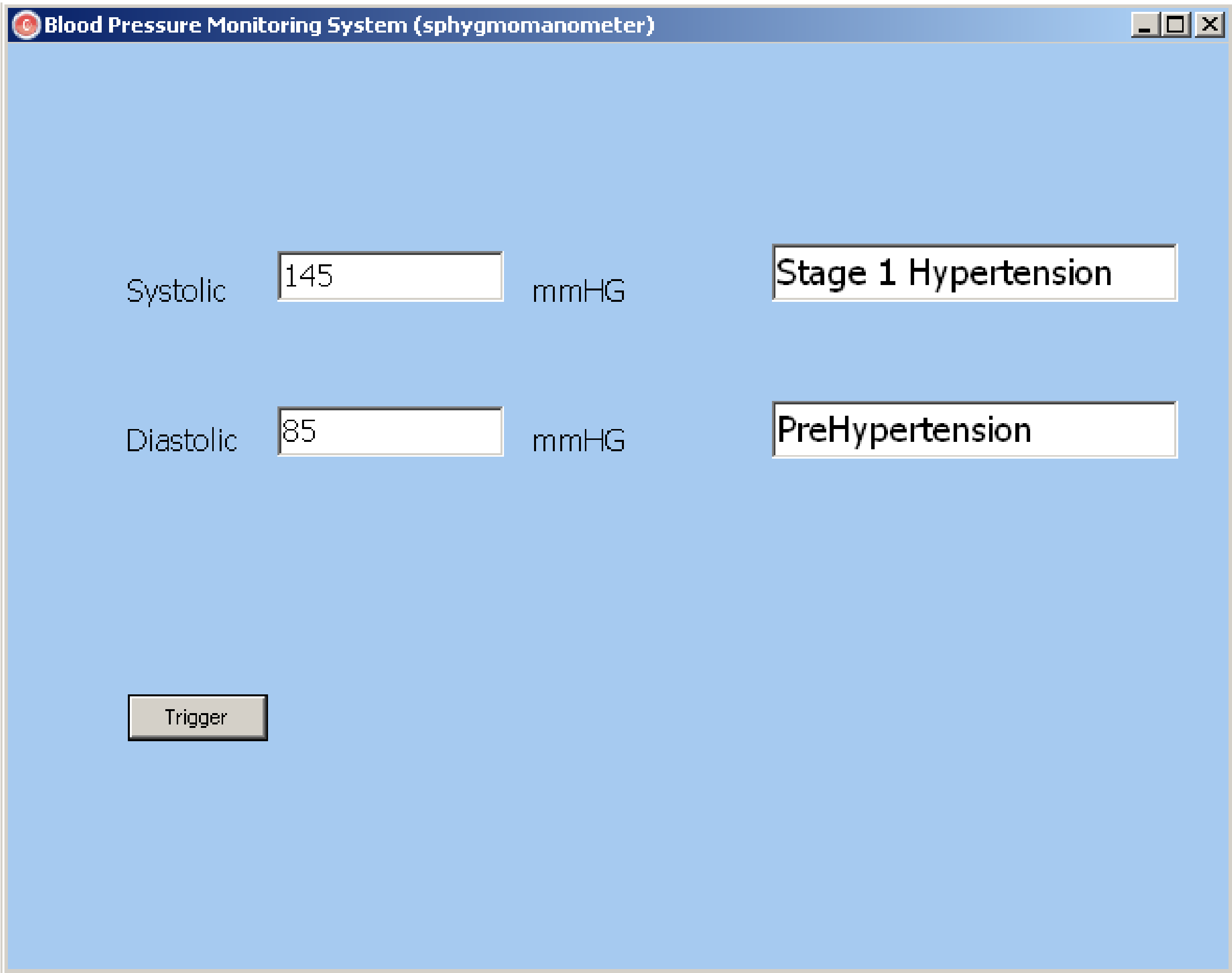

Figure 5 Blood Pressure Monitoring System (sphygmomanometer)
Case 2: Depicting Stage 1 Hypertension and Pre-Hypertension.

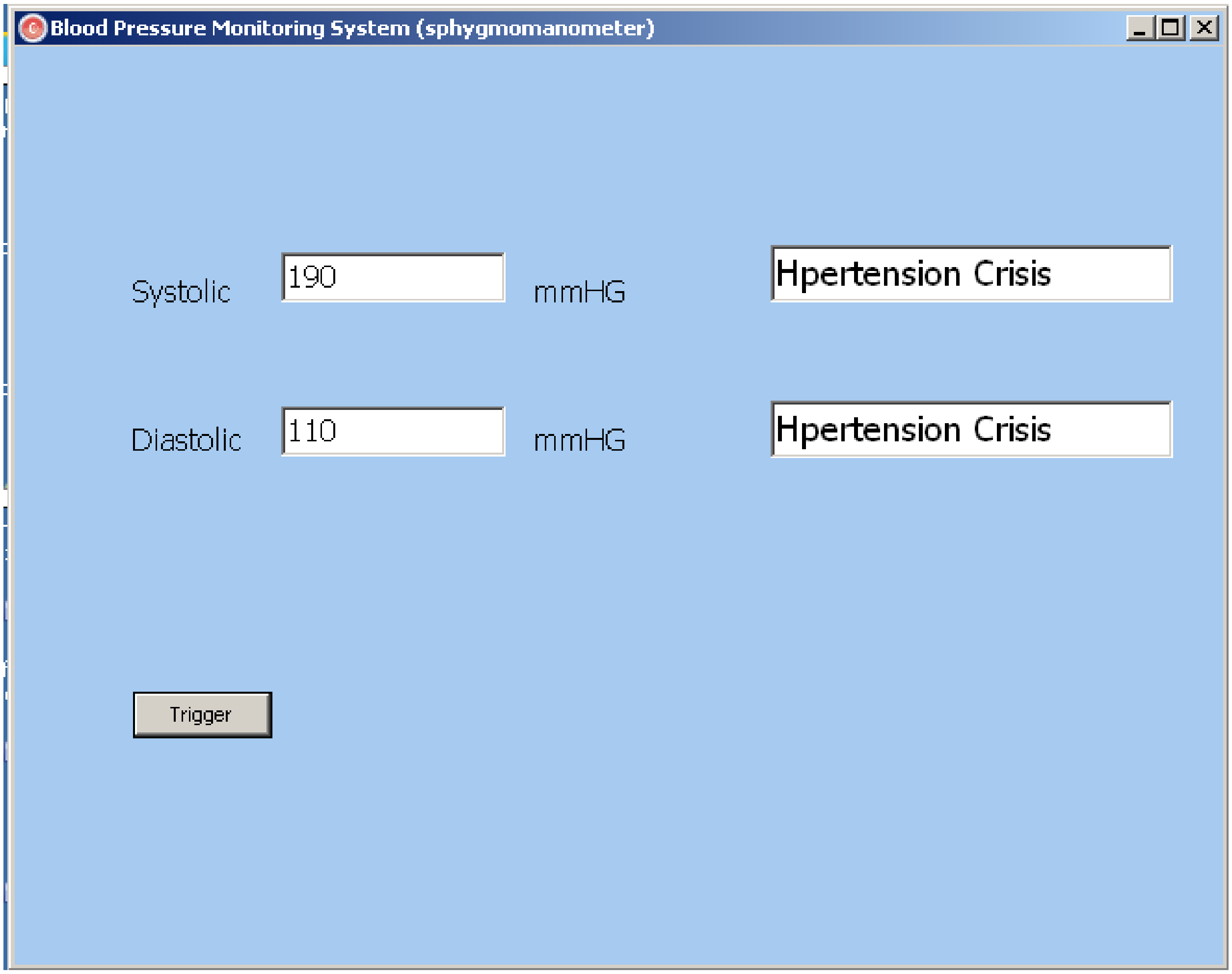

Figure 6 Blood Pressure Monitoring System (sphygmomanometer)
Case 3: Depicting Hypertension Crisis.

Course Assignments

The course requires a weekly position paper that expounds the conceptual understanding of the subject matter content and inferences drawn from the laboratory performance. The course assignments are submitted on line. Each student maintains an online portfolio of the work.

Pedagogy of the Course

The pedagogy of the course is based on Outcome Based Education[8], and utilizes the interactive model of learning[9]. All the students maintain an online portfolio of their work. The system designed in the laboratory to perform a specific task is the core measurement as the learning outcome of the course. The laboratory performance of the course is performed in teams of two/three students. This mode provides a platform for horizontal learning through active and engaged discourse and discussion. Students are empowered to charter their learning and feed their curiosity. These classroom practices and laboratory environment provides a challenging and invigorating environment that prepares them for a lifelong learning process and career path.

Assessment

The student satisfaction index gathered in the survey indicated that the course, lab sequence is quite demanding in terms of time allocated for the course**.** The side by side student satisfaction index gathered for the course compared with the tradition course offering showed a 15.40% advantage. On this single indicator alone the **SDA** approach of delivery is significant enough to be given serious consideration.

Conclusion

The **SDA** approach addresses the disadvantages of teaching through a proprietary instrument system. The accompanying commercial software is not accessible to student and does not contribute to their skill sets as a software system designer. The cost associated with establishment, and upkeep of a commercial instrumentation is prohibitive. The replacement due to obsolescence of the equipment due to technological advancement is an ongoing budgetary problem. The content of the course presented to the students has the philosophical undertone to provide the intricacies of system design on an open platform providing with the open source software methodology[10].

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