International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

Heartbeat Analyzer: Low-Cost PC-Based ECG Machine

Tahir Bashir[1]

Bachelor of Computer Engineering

Bahria University Karachi Campus, Karachi, Pakistan

Abstract: ***This project presents the design and development of a portable, real-time, PC-based ECG monitoring device that addresses several critical issues faced by traditional monitors, such as baseline wandering, muscle noise, changing electrode resistance, and lead problems. These challenges typically decrease the reliability of ECG systems. To overcome them, we employed high-gain instrumentation amplifiers like AD624AD and AD620, which improve the real-time processing of ECG morphology and ensure power-efficient performance. The system captures the ECG signal, transmits it via the computer's parallel port, and displays it across three separate lead graphs using custom software. Reliable detection of R-peaks is achieved through multiple statistical techniques, ensuring accurate heart rate measurement. The system identifies R-peaks within a defined time and amplitude range and uses the average RR interval to determine heart rate. Additionally, energy consumption and battery life were evaluated using a profiling environment, providing valuable insights into the system's efficiency. This environment includes a PC, digital oscilloscope, and other testing tools to measure and improve performance.***

Keywords: Heartbeat Analyzer (HBA), Electrocardiogram (ECG), Real-time monitoring, Low-cost ECG machine, Signal amplification, Analog-to-digital converter (ADC), Biomedical equipment, PC-based ECG, Signal processing, Visual Basic software.

1. Introduction

Heart failure is one of the leading causes of death, and it is often challenging to determine whether the cause of death or illness is due to heart disease or another condition. The invention of the electrocardiogram, or ECG (also known as EKG, from the German term), has made it easier for doctors to diagnose heart-related issues in time to save patients' lives. Initially, ECG machines were too large and difficult to handle, but over time, they have become more compact. However, biomedical equipment, including ECG machines, remains expensive, making it difficult for most hospitals in Pakistan to afford them. Therefore, we decided to design an ECG machine that is both low-cost and compact in size. The primary challenge in designing biomedical equipment is ensuring that it meets medical standards, as this equipment directly interacts with patients. The safety and protection of patients is a critical concern. As computer systems engineering students, interfacing the device was not a significant issue, but the main challenge we encountered was acquiring the weak signals (± 5mV) from the body.

2. Background

The existing system for analyzing heartbeats, developed by Siemens, is called the Data Scope Passport 2. It is an isolated system that analyzes heart activity without needing other devices. As an embedded system, it requires minimal computing power and operates independently. However, this system has several drawbacks. First, it is too expensive for small hospitals and clinics to afford. Second, if there is a hardware issue, it requires imported engineering, which is also costly. Additionally, the Data Scope Passport 2 only displays results on-screen and does not allow saving patient records in digital form. Due to its high cost, it is used only for serious cases, and for certain conditions, local doctors may not be able to resolve the problem, necessitating consultation with foreign doctors, which is expensive.

The Heartbeat Analyzer (HBA) offers a solution to all these issues. Using software to analyze heartbeats, it is far less expensive than the Data Scope Passport 2. It allows users to maintain records of multiple patients, provides the option to print ECG results, and is affordable enough for daily use by doctors for routine heart tests. Patients themselves can also use it for daily monitoring when a doctor is unavailable. HBA helps maintain patient records, allowing doctors to review past results at any time and assess current or future conditions. Additionally, HBA enables patients to consult with foreign doctors by providing access to soft copies of their heart records online.

3. System Overview

The HBA system is built around two key components: hardware and software. The hardware is responsible for acquiring the weak electrical signals produced by the human heart and amplifying them for further analysis. These signals, typically ranging from 1 to 5 millivolts, are too weak for direct processing by a computer. As such, they must first be amplified and filtered to remove noise before being converted into a digital signal.

The software, developed in Visual Basic, processes the digital signal and displays the resulting ECG waveform in real-time. It also provides options to save, print, and reload patient data for future analysis. By integrating these two components, the HBA system offers a comprehensive and affordable solution for heart monitoring.

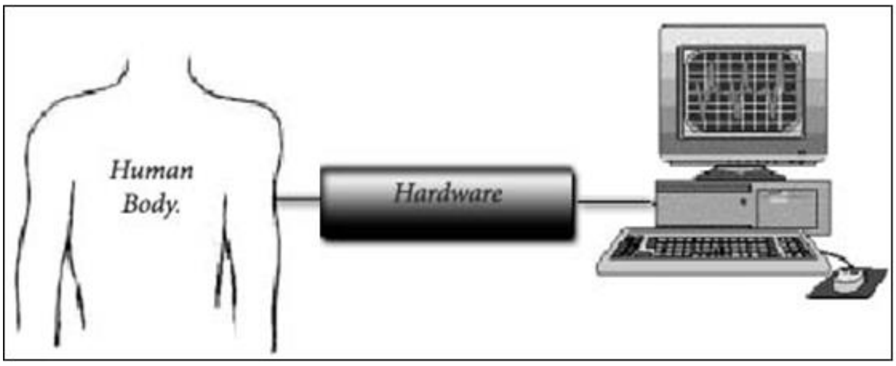

Figure 1: System overview design

Block Diagram of the Heart Beat Analyzer

The block diagram below illustrates the flow of signals through the Heartbeat Analyzer system. Starting from the acquisition of heart signals via electrodes, the signals pass through several stages of amplification and filtering before being converted to digital data for display on the PC.

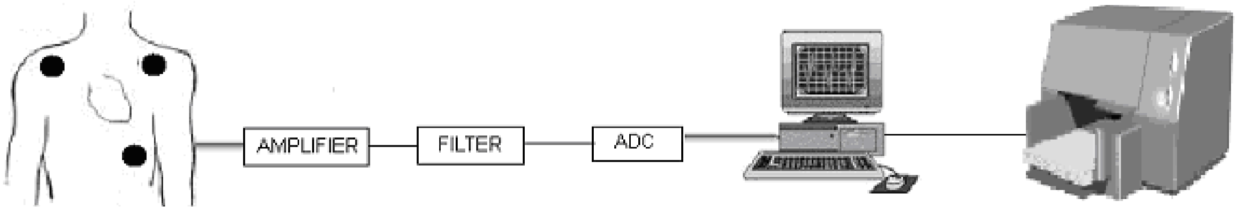

Figure 2: Block Diagram of Heartbeat Analyzer

Importance of the research

The importance of this research lies in its potential to address the significant gap in access to affordable biomedical equipment, especially in developing countries. Heart disease is one of the leading causes of death worldwide, and early diagnosis through electrocardiograms (ECG) can save countless lives. However, many healthcare facilities, particularly in resource-limited settings, cannot afford the expensive ECG machines available in the market. By designing a low-cost, PC-based ECG machine like the Heartbeat Analyzer (HBA), this research makes reliable, real-time heart monitoring accessible to hospitals and clinics that otherwise could not afford such technology. The research is crucial in promoting healthcare equality, providing both patients and doctors with the tools needed for timely diagnosis and treatment of heart conditions, ultimately contributing to improved patient outcomes and reduced mortality rates.

4. Literature Review

This The field of electrocardiography has undergone several technological advancements since its inception. Early ECG machines were large, bulky, and difficult to operate. Over the years, the size and cost of these machines have decreased significantly, thanks to advancements in instrumentation amplifiers, signal processing, and microelectronics.

Siemens introduced the Data Scope Passport 2, one of the earliest machines designed for real-time ECG monitoring. While effective, it was expensive, limiting its use to well-funded hospitals. The Heartbeat Analyzer was conceived as an affordable alternative, offering similar diagnostic capabilities at a fraction of the cost.

System Design and Implementation

This section outlines the system design and implementation process for the Heartbeat Analyzer (HBA). The design includes a detailed feasibility study, architectural strategies, and various modeling techniques such as Object-Oriented Design, Use Case Modeling, and Class Diagrams. The implementation addresses both the hardware and software components of the system.

- **Feasibility Study:** A thorough feasibility study was conducted to evaluate the technical and economic viability of the HBA project. The study assessed the potential impact, risks, and technical challenges associated with developing a real-time ECG system.
- **Technical Feasibility**: Various platforms such as MATLAB, Java, and Visual C were considered for the software implementation. However, due to limitations such as long compilation times and lack of parallel port access, Visual Basic 6 was chosen as the development environment. Visual Basic 6 provides the necessary functionality to access the parallel port and manage real-time graphics, while also offering printing capabilities.
- **Economic Feasibility**: The Heartbeat Analyzer offers a cost-effective solution compared to existing market alternatives. The system reduces the cost by approximately four lakh rupees compared to other systems. Additionally, HBA provides the ability to save and print soft copies of ECG waves, further lowering costs associated with consulting foreign doctors.
- **Organizational Feasibility**: Given the user-friendly design of the Heartbeat Analyzer, personnel at hospitals who are generally familiar with computers can easily operate the system. The system's interface simplifies tasks such as taking, saving, printing, and recalling ECG data.

SWOT Analysis: The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis evaluates the overall design of the system.

- **Strengths**: The HBA uses existing computer systems in hospitals, has adaptable software, and meets the requirements of heart specialists based on detailed surveys.
- **Weaknesses:** The system depends on the speed of the computer, has limited storage for ECG waves, and is constrained using batteries for power supply.
- **Opportunities**: Working on this project provided the opportunity to learn multiple programming languages and reduce the cost of embedded systems by converting them to PC-based solutions.
- **Threats:** A key threat to the project is the potential for competing PC-based ECG systems and the risk of market entry before the product is introduced.
- **Design Considerations:** The design of the Heartbeat Analyzer considers the typical hospital environment, particularly Intensive Care Units (ICUs). Since muscle movements are negligible in ICU patients, the system is designed to handle minimal interference. A notch filter is included to reduce noise caused by air conditioning systems.

Object-Oriented Analysis and Design

The system employs an object-oriented design, where the software components are treated as objects with defined states and operations. The design process involved developing various models such as the HBA model diagram, which shows the interconnectivity of hardware and software, as well as the use case model diagram, which represents user interactions with the system.

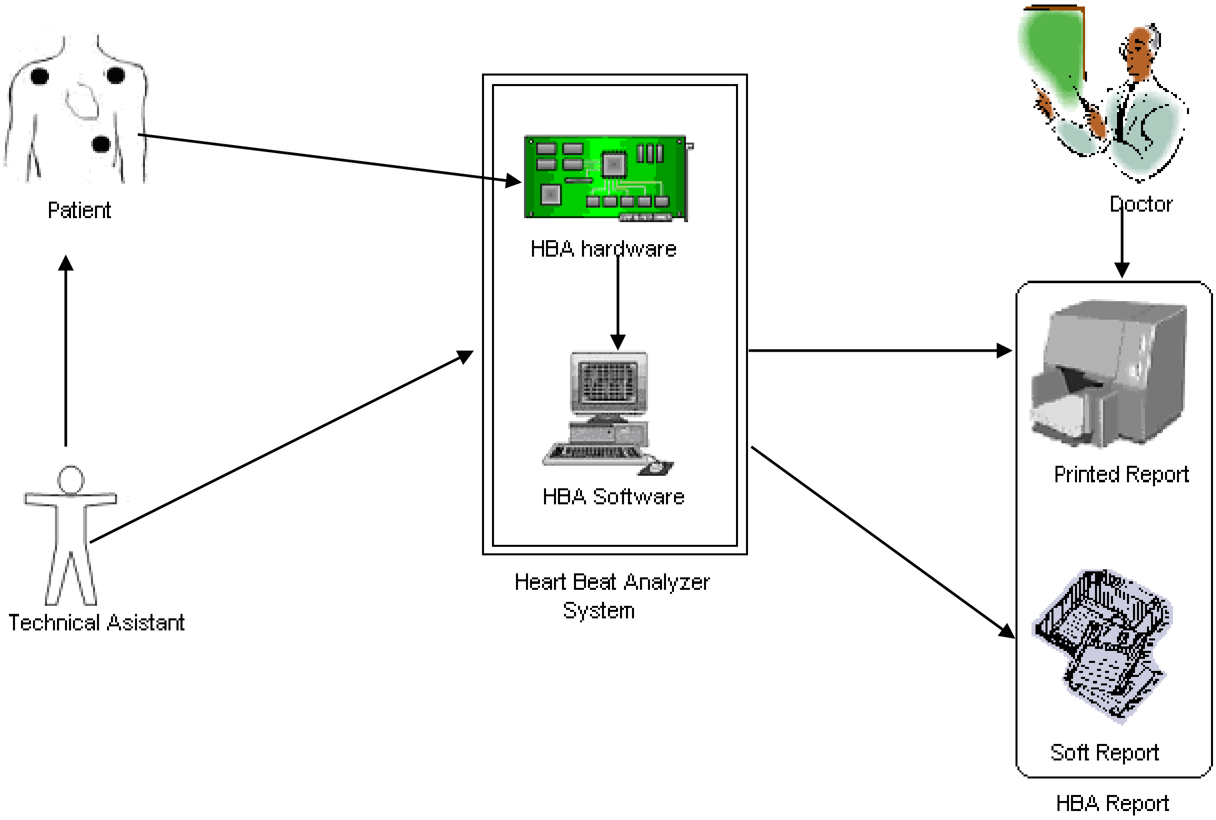

Figure 3: Heartbeat Analyzer Model Diagram

Class Diagram: The class diagram for the Heartbeat Analyzer illustrates the structure and relationships between different classes in the system, including attributes and operations for each class.

Use Case Modeling

The unified modeling language is now the most widely used graphical representation scheme for modeling the object-oriented systems. It has indeed unified the variance popular notational schemes those who design systems use the language to model their systems. Use case diagrams represent the interaction between the user and our system (i. e. all actions the user may perform on the system) when developers begin the project, they rarely start with detailed a problem statement.

Data Flow Diagram

This data flow diagram shows the process of the Heartbeat Analyzer (HBA). The human ECG wave is first amplified, filtered using Sallen Key and line filters, then converted to digital form by an Analog to Digital Converter (ADC). The digital signal is processed by the HBA software for display and analysis. Each step ensures accurate signal processing and noise reduction.

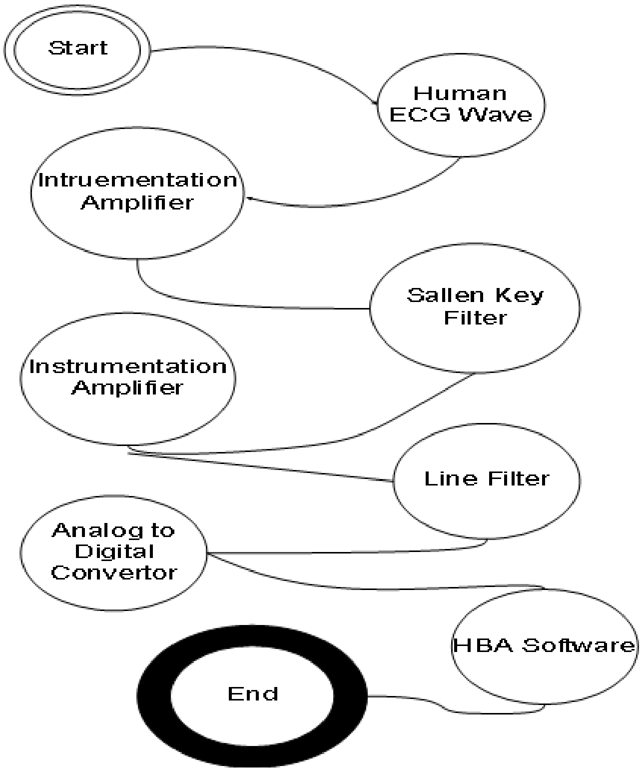

Figure 4: Data Flow Diagram

5. Implementation

The purpose of this project is to design, build, and test a low-cost, digital, real-time ECG monitor. The software for the system was developed using Visual Basic, and the hardware components selected were moderate in cost while maintaining the accuracy required to capture ECG signals from the human body.

Hardware Development

The hardware development focused on minimizing costs while ensuring reliable signal processing. The AD624AD instrumentation amplifier was chosen for its high gain of 1000, providing the necessary amplification of weak ECG signals from the human body. The system also includes an 8-channel, 8-bit analog-to-digital converter (ADC), which converts the amplified analog signals into digital form for further processing on the computer. The channel selection for the ADC is managed through Visual Basic.

Design Considerations

Accuracy, dependability, and precision are crucial in medical devices, and small fluctuations in the ECG waveform can carry critical diagnostic value. The ECG system must display cardiac signals faithfully, so any detected irregularities can be attributed to actual cardiac issues rather than equipment errors. Several factors were considered in the design to ensure the system's reliability:

- **Noise:** Since ECG signals are small in amplitude, noise interference could easily mask the true signals. To prevent this, strict limitations were imposed on noise levels, and every effort was made to minimize noise in the data acquisition process.
- **Signal Amplitude:** Cardiac signals have small peak amplitudes, requiring significant amplification to ensure accurate analysis and output. Amplifying the signal up to 5 volts improves the quality of the analog-to-digital conversion.
- **Low Frequency Response:** Since cardiac signals have a low bandwidth, the system was designed with a strong low-frequency response, particularly for the critical S-T portion of the waveform, which holds important diagnostic information.

Design Implementation

The hardware system follows a structured design flow. Electrodes placed on the body capture the ECG signal, which is first amplified by the AD624AD amplifier. The signal is then passed through a Sallen-Key filter for noise reduction and further amplified using an AD620 to reach the required 3 to 5 volts for digitization. The amplified signal is sent to an ADC (ADC0808) for conversion to digital form before being transmitted to the computer through a parallel port for processing by the software. Figure 5 represents the entire system design, which can be use for more illustration.

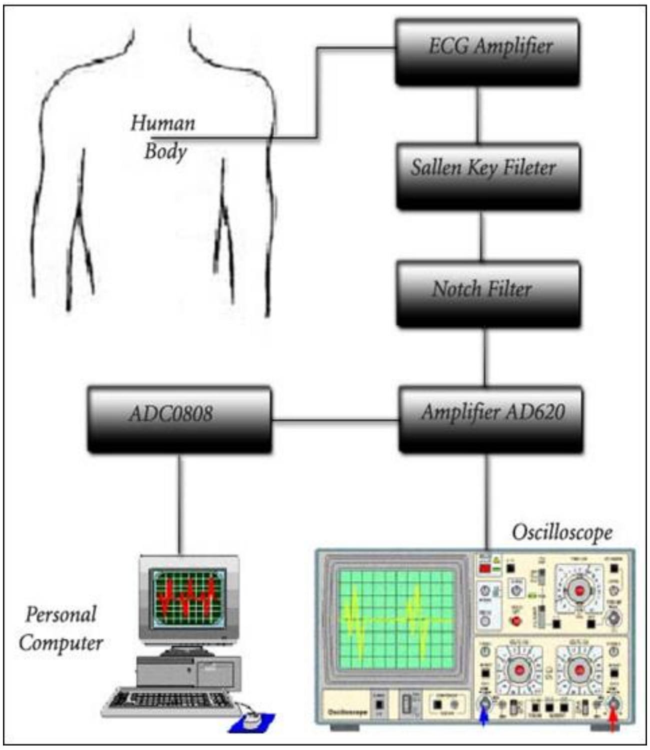

Figure 5: Block Diagram of entire System

Interfacing Between Human and ECG Hardware (Electrodes)

The electrodes act as bio-electric transducers, converting the ionic electrical signals from the body into electrical current that can be processed by the hardware. Ag-AgCl electrodes were used due to their stable and non-polarizable nature, which helps in reducing noise and increasing the signal-to-noise ratio.

Filters and Amplification

A Sallen-Key filter was implemented to serve as a buffer and non-inverting amplifier for the amplified signal. A notch filter was also included to eliminate line noise, particularly the 50-60 Hz frequency interference from power lines. After noise filtration, the signal is further amplified using the AD620, preparing it for analog-to-digital conversion.

Paper ID: SR16315171140 DOI: https://dx.doi.org/10.21275/SR16315171140

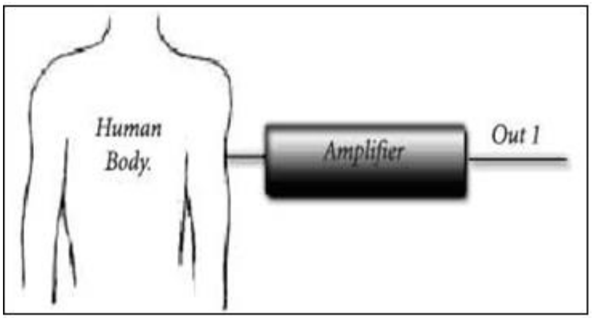

Figure 5: Interface between AD624 and Human

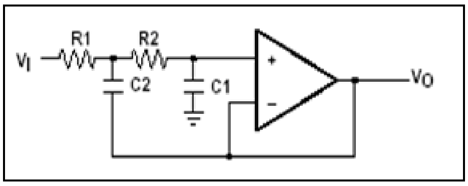

Figure 6: Unity gain Sallen Key Low pass filter

Analog-to-Digital Conversion

The system utilizes an ADC0808 converter to digitize the analog ECG signals. The converter operates with three different channels corresponding to the three ECG leads (Lead I, Lead II, and Lead III), and each channel is selected by address lines controlled through the Visual Basic software. This digital data is then transmitted to the computer for real-time visualization. In order to interface hardware with computer, noise free ECG signal is required to convert into digital form. In order to convert it into digital form, we required to increase the strength of ECG signal till 3V – 5V because ADC0808 takes the input that has appropriate strength. But the output of notch filter is 1 – 2V, so here we require amplifying it with the appropriate gain. For this purpose we are using AD620 which amplify the 1-2V signal into 3 – 5V. The AD620 requires only a single external gain-setting resistor; Resistors R2 and R3 change the normal gain equation to Gain = 1 + 49.4 k/RG + (49.4 k/2) /22 k.

To avoid output saturation, the usable gain is limited by the output swing and the maximum input voltage to the IA. With a + 5V power supply, the output swing of the AD620 is about + 3.8 V; and the maximum input is +5 mV plus a variable normal-mode

DC offset of up to + 300 mV, allowing a maximum gain of 12.45. Here, the gain is conservatively set to 8 (+1%), using RG = 8.45 k. Following is the pin diagram of AD620.

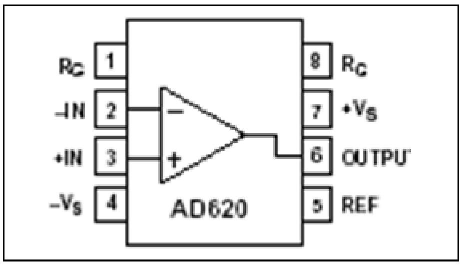

Figure 7: AD620

Now the output of Notch filter becomes the input of AD620 that performs amplification and promote this signal to the ADC0808. Datasheet and Notes of AD620 can be found in Appendix B-2. Complete illustration of this module is as follows,

Figure 8: Interface between AD620 & ADC

Software Development

The development of the Heart Beat Analyzer (HBA) software focused on creating a simple, resource-efficient application using Visual Basic. The philosophy behind the software development was to keep the code minimal and comprehensible, ensuring it did not overburden system resources. The code was built step-by-step, with small programs tested at each stage to ensure functionality. This approach minimized the risk of encountering large-scale bugs that could prove difficult to debug. While high-level programming languages like C were considered due to their ease of modification and reusability, Visual Basic was chosen for its efficiency in resource management, as the C code generated was significantly larger and less efficient.

Parallel Port Communication

The primary function of the software was to initialize the computer's parallel port (378H) using predefined functions and procedures in the WINIO. DLL library. The parallel port receives ECG signals in binary form, which are then converted into decimal format by the program for further processing. If the parallel port is occupied by another program, the system displays an error message indicating that the port could not be initialized.

Plotting the Received Signal

Once the ECG signal is received from the parallel port and converted to decimal values, the program plots the signal in real-time using Visual Basic's SetPixel method. Three picture boxes are used to display data from three different ECG leads—Lead-I, Lead-II, and Lead-III. Addressing modes in the ADC-0804 are used to select different channels for the corresponding leads, enabling the system to plot the signal data for each lead simultaneously.

Patient Record Management

The software includes a patient record management feature where critical information such as name, age, disease, hospital ID, and emergency contact information can be stored. This form must be filled out before ECG data can be accessed, ensuring that patient information is logged for future reference.

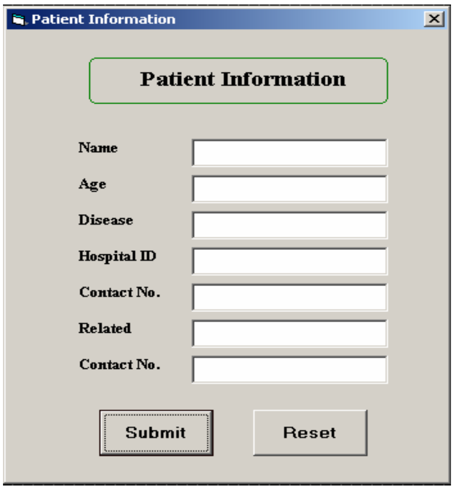

Figure 9: Patient Information Page

Heart Rate Calculation

Heart rate is calculated based on the number of R-peaks detected in the ECG signal over a one-minute interval. The R-peaks, representing the highest amplitude in the ECG waveform, are identified by comparing stored signal values in a two-dimensional array. The total number of R-peaks corresponds to the heart rate in beats per minute.

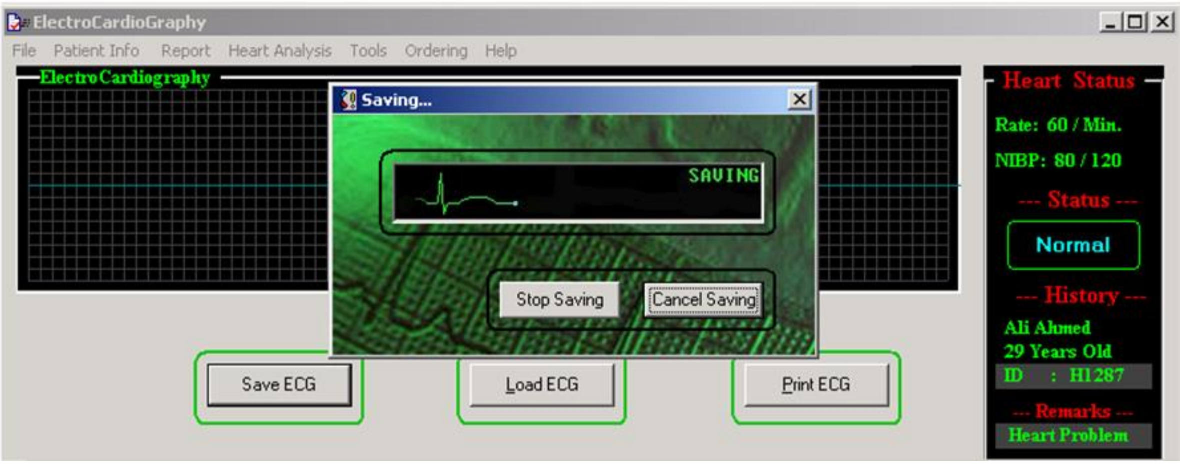

Figure 10: ECG recording Page

ECG Saving Procedure

One of the unique features of the HBA software is its ability to store ECG signals for an unlimited period. The ECG signals (stored as decimal values) are saved in text files using Visual Basic's predefined filing procedures. The software prompts the user to name the file, and the data is continuously written to the file until the user stops the saving process.

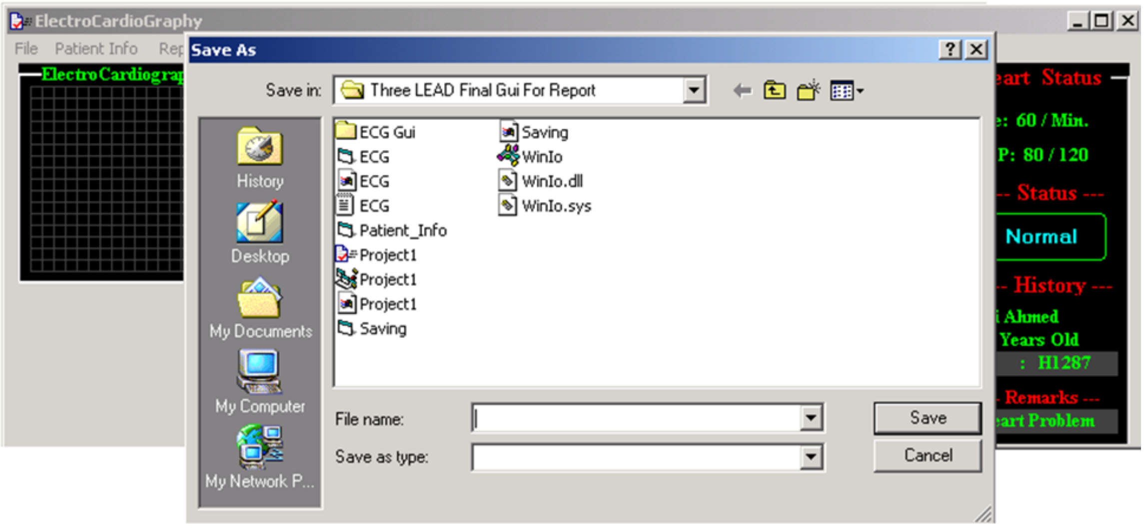

Figure 11: ECG saving Page

Loading and Printing Stored ECG Data

The software also allows for loading previously saved ECG signals and displaying them as graphs for further analysis. Additionally, the user can print the stored ECG data on ECG paper by selecting the file and sending it to the default printer. The printing process is automated and managed through Visual Basic code, with variables set for both x and y-axis values to ensure proper alignment on the page.

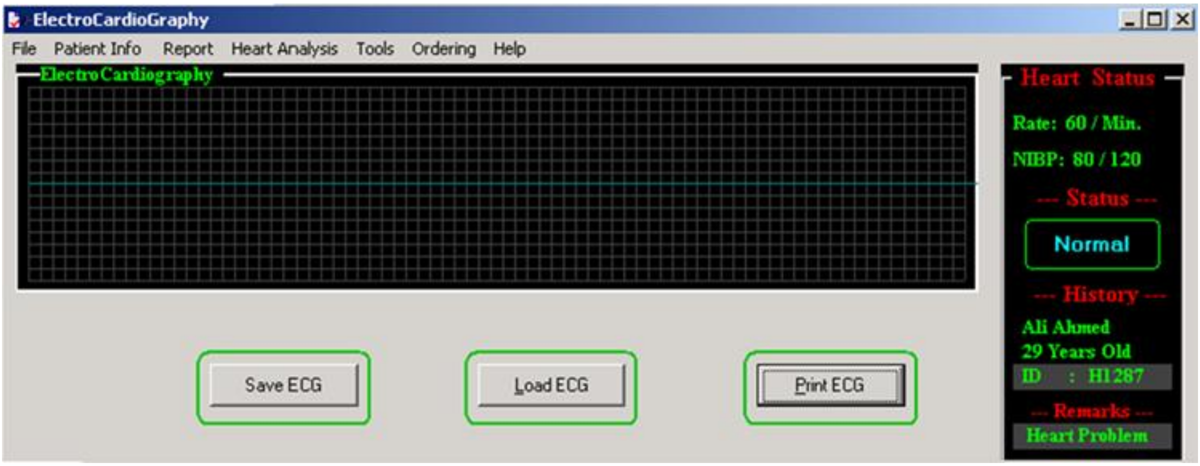

Figure 11: ECG Loading and Printing Page

Software Interface Overview

The HBA software interface is user-friendly, featuring a main screen that displays heart status, patient history, and intervals. After filling out the patient information form, the user can access options to plot, save, load, or print ECG data. The interface also includes a standard drop-down menu with options for file management, patient information, reports, and heart analysis. The heart analysis menu provides detailed insights into the patient's heart rate, PR-Peak, QRSD-Peak, QT-Peak, and other vital metrics.

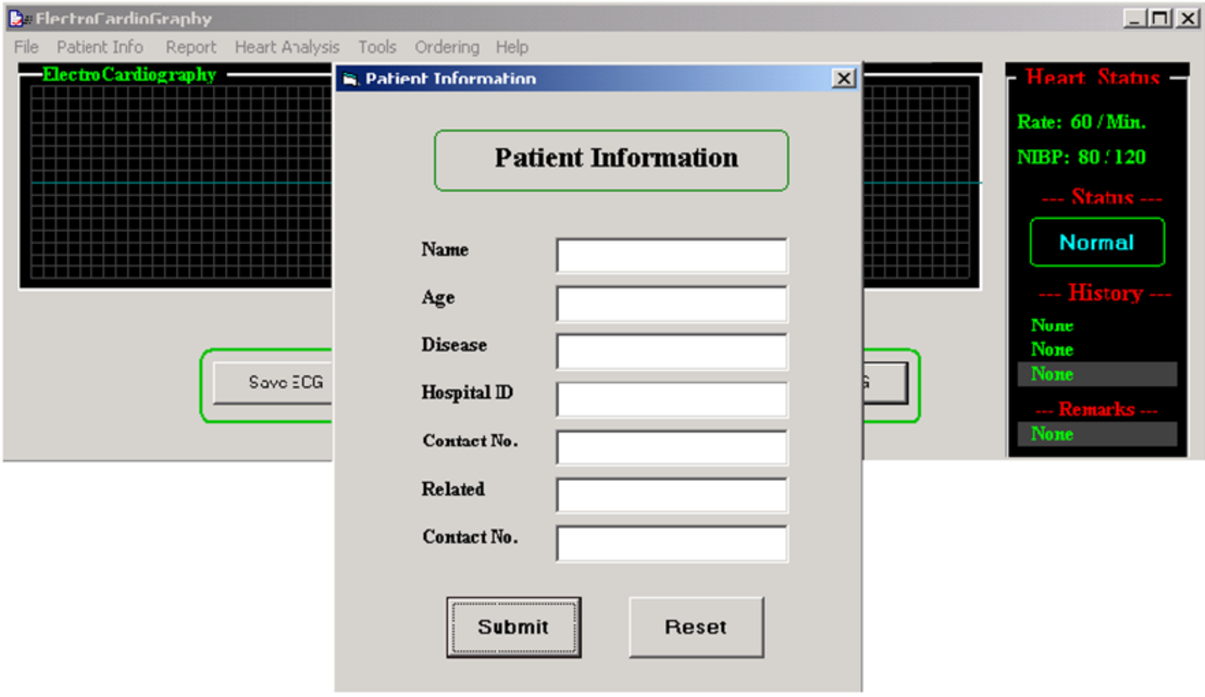

Figure 10: Main Page of Software

Help Menu

The software includes a comprehensive help menu that guides users through various tasks such as applying electrodes, using the software, saving and printing ECG data, and troubleshooting. The help menu also provides shortcuts for quicker navigation, enhancing the overall usability of the software.

6. Testing Results

The testing phase of the Heartbeat Analyzer (HBA) project involved validating the functionality of the hardware components, software, and the overall system. Various tests were conducted to ensure the reliability, accuracy, and compatibility of the system. The circuit was constructed on a strip board, as shown in the setup below, and multiple tests were performed using digital dual-trace oscilloscopes, DC power supplies, signal generators, and a personal computer running Rims Demo.

Lead, Electrode & Gel Test

Given the weak strength of the input signals, special attention was paid to the input components: electrodes, leads, and gel. The electrodes act as bio-electric transducers, while the gel improves conduction between the electrodes and the human body. Leads carry these weak signals into the hardware. We performed the following tests to evaluate the quality and performance of these components:

Leads Test: A millivolt input signal was applied to one end of the lead, and the same output was measured at the other end to ensure signal integrity.

Electrodes Test: Electrodes were attached to the human body at specified positions, and the output was tested using a multimeter to verify signal transmission.

Parallel Port Communication Test
The parallel port communication between the computer and the external hardware was tested using Visual Basic and the Rims Microprocessor board. A Visual Basic program was designed to fetch data from the parallel port and display it graphically. The Rims Microprocessor board generated a digital sine wave, which was transmitted to the computer's parallel port. The program successfully retrieved and displayed the sine wave, validating the parallel port communication.

Amplification Test of AD624AD
AD624AD, the primary amplifier in the hardware system, was tested for its amplification performance. A millivolt signal from a function generator was provided as input, and the output was measured in volts using a digital dual-trace oscilloscope. The gain of the amplifier was verified by adjusting the resistance with a potentiometer, demonstrating successful signal amplification.

Amplification Test of AD620
Like AD624AD, the AD620 instrumentation amplifier was tested. However, in this test, the input signal was provided in the range of 1-2 volts, and the output was measured in the range of 5-6 volts. This test confirmed the ability of AD620 to provide sufficient amplification for further processing in the system.

Analog-to-Digital Conversion Test
The ADC0808 was tested to ensure accurate conversion of the analog ECG signal to digital form for computer processing. An analog input signal was supplied using a function generator, and the digital output was received via the computer's parallel port. This test confirmed the successful interfacing of the hardware with the personal computer.

Printer Test
A key feature of the HBA system is the ability to print ECG signals for further analysis by doctors. The printer functionality was tested using Visual Basic code, which sent the received signal from the parallel port to the default printer. The system successfully printed stored sine wave data, demonstrating the effective implementation of the printing feature.

7. Conclusion

The goal of this project was to design, build, and test a low-cost, computer-based ECG monitoring system, and this objective was successfully achieved. Using carefully selected hardware components, such as the AD624AD instrumentation amplifier and the ADC0808 analog-to-digital converter, the system was able to capture, amplify, and display the heart's electrical activity in real-time. While the design has proven functional under testing, further development is needed to address some limitations, such as noise reduction and display optimization.

The project demonstrated that simple, low-cost ECG systems can be built using readily available components, providing a reliable method for monitoring heart activity. The real-time visualization and storage of ECG signals offer a non-invasive diagnostic tool that can aid in detecting heart abnormalities. Although challenges, such as signal interference and the limitations of CRT display technology, were encountered, the system's performance can be further enhanced with additional improvements, such as utilizing LCD or TFT displays and refining the software for better refresh rates.

In conclusion, the project has laid the groundwork for a functional, cost-effective ECG monitor that could be further developed for practical use in both clinical and personal health monitoring. Future work should focus on improving the system's precision, minimizing noise, and expanding its usability in real-world medical applications.

References

[1] AD624AD Instrumentation Amplifier Datasheet. Analog Devices, Inc. Available at: www.analog. com.
[2] ADC0808/ADC0809 Data Acquisition Systems. Texas Instruments. Available at: www.ti. com.
[3] Electrocardiography (ECG) Signal Processing. John G. Webster, Medical Instrumentation: Application and Design.4th Edition, Wiley, 2009.
[4] Visual Basic for Applications. Microsoft Corporation. Available at: www.microsoft. com.
[5] Sallen-Key Filter Design. R. P. Sallen and E. L. Key, A Practical Method of Designing RC Active Filters, 1955.
[6] Digital Oscilloscopes and ECG Signal Display. Tektronix, Understanding Digital Oscilloscopes for Medical Use, 2011.
[7] Parallel Port Interfacing in Embedded Systems. R. Smith, The Art of Parallel Port Interfacing in Embedded Systems, 2005.
[8] Instrumentation Amplifiers in Medical Applications. Alan T. Baker, Biomedical Signal Processing, Elsevier, 2014.
[9] Heart Rate Measurement Using R-Peak Detection. B. Patel, Digital Processing of Biomedical Signals, Springer, 2010.
[10] Noise and Signal Amplification in ECG Systems. M. Roberge, Amplification Techniques in Low Signal Biomedical Devices, IEEE Transactions, 2015.
[11] Signal Processing for ECG. J. Malmivuo and R. Plonsey, Bioelectromagnetism: Principles and Applications of Bioelectric and Biomagnetic Fields, Oxford University Press, 1995.
[12] DC Power Supplies in Medical Devices. K. Haycock, Power Supplies for Medical Applications, Elsevier, 2007.
[13] ECG Data Acquisition Systems. Siemens Medical Solutions, Data Scope Passport 2 User Manual, Siemens Corporation, 2012.

[14] Microprocessor-Based Data Acquisition for ECG Systems. D. Anderson, Microprocessor Control for Medical Equipment, McGraw-Hill, 2008.
[15] Heartbeat Analysis and Digital Processing. P. Clayton, Digital Techniques for Biomedical Engineering, Prentice Hall, 2005.