DEVELOPMENT OF FINGER HEART RATE SENSOR MONITOR USING GRAPHICAL USER INTERFACE (GUI) IN MATLAB

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Abstract – The aim of this paper is to develop the finger heart rate sensor monitor system using Graphical User Interface (GUI) in MATLAB. The samples of normal pulse wave from the developed finger heart rate sensor monitor are loaded into the system where MATLAB mathematical software is used to perform the analysis to calculate and display the heart rate. The finger heart rate sensor monitor developed, outputs an analog signal that represent the cardiovascular pulse wave that is found throughout the human body. This pulse wave will result in a change in the volume of arterial blood with each pulse beat The heart rate is calculated based on the difference between the time occurrence of the peak amplitude of two consecutive pulses. In this paper, the performance of this monitoring system is tested by using the real data. An analog to digital converter (ADC) is also designed to interface the analog signal obtained from the hardware to the computer for real-time processing. However the ADC needs to be further improved for better output performance.

Keywords –Graphical User Interface (GUI), Analog Digital Converter (ADC), Light emitting diode (LED), Light sensitive detector (LSD) Lowpass filter (LPS)

1.0 INTRODUCTION

The Finger Heart Rate sensor monitors the light level transmitted through the vascular tissue of the fingertip and the corresponding variations in light intensities that occurs as the blood volume changes in the tissue. The Finger Heart Rate Sensor monitor is used to measure the cardiovascular pulse wave that is found throughout the human body. This pulse wave will result in a change in the volume of arterial blood with each pulse beat. This change in blood volume can be detected in peripheral parts of the body such as the fingertip using a technique called Photoplethysmography. The device that detects the signal is called a plethysmograph (or 'Pleth' for short). The Pleth consists of an infrared LED which illuminates the tissue and A light sensitive detector (LSD), which has been tuned to the same colour frequency as the LED, and detects the amount of light transmitted from the tissue The Pleth supplied with this sensor is a transmission mode plethysmographic signal (PPG) device, which uses transmitted light to estimate absorption. The infrared LED and the light sensitive detector (LSD) are mounted in a spring loaded device that can be clipped onto the fingertip The infrared light emitted by the LED is diffusely scattered through the fingertip or ear lobe tissue. A light sensitive detector positioned on the surface of the skin on the opposite side can measure light transmitted through at a range of depths. Infrared light is absorbed well in blood and weakly absorbed in tissue. Any changes in blood volume will be registered since increasing (or decreasing) volume will cause more or less absorption. Assuming the subject does not move the level of absorption of the tissue and non-pulsating fluids will remain the same.

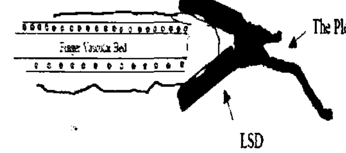

Figure 1.0.0: Fingertip between the LED and LSD

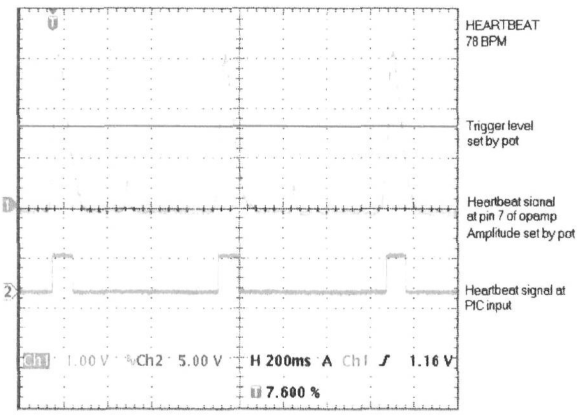

Figure1.0.1 Output waveform for Finger heart rate sensor monitor

1.1 Analog and Digital signal

Most data acquisition signals can be described as analog, digital or pulse. While analog signals typically vary smoothly and continuously over time, digital signals are present at discrete points in time (Figure 1.1). In most control applications, analog signals range continuously over a specified current or voltage range, such as 4-20 mA dc or 0 to 5 V dc. While digital signals are essentially on/off (the pump is on or off, the bottle is there or isn't), analog signals represent continuously variable entities such as temperatures, pressures, or flow rates. Because computer-based controllers and systems understand only discrete on/off information, conversion of analog signals to digital representations is necessary.

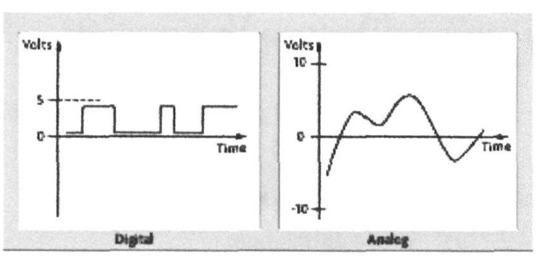

Figure1.1 Digital and analog representations

1.3 Analog to Digital Conversion

Continuous electrical signals are converted to the digital language of computers using analog-to-digital (A/D) converters. When determining what type of A/D converter should be used in a given application, performance should be closely matched to the requirements of the analog input. Accuracy, signal frequency content, maximum signal level, and dynamic range all should be considered. Central to the performance of an A/D converter is its resolution, often expressed in bits. An A/D converter essentially divides the analog input range into 2N bins, where N is the number of bits. In other words, resolution is a measure of the number of levels used to represent the analog input range and determines the converter's sensitivity to a change in analog input. Amplification of the signal, or input gain, can be used to increase the apparent sensitivity if the signal's expected maximum range is less than the input range of the A/D converter. Absolute accuracy of the A/D conversion is a function of the reference voltage stability (the known voltage to which the unknown voltage is compared) as well as the comparator performance. Overall, it is of limited use to know the accuracy of the A/D converter itself. Accuracy of the system, together with associated multiplexer, amplifier, and other circuitry is typically more meaningful. The other primary A/D converter performance parameter that must be considered is speed-throughput for a multi-channel device. Overall, system speed depends on the conversion time, acquisition time, transfer time, and the number of channels being served by the system: Acquisition is the time needed by the front-end analog circuitry to acquire a signal. Also called aperture time, it is the time for which the converter must see the analog voltage in order to complete a conversion. Conversion is the time needed to produce a digital value corresponding to the analog value. Transfer is the time needed to send the digital value to the host computer's memory. Throughput, then, equals the number of channels being served divided by the time required to do all three functions. This analog-to-digital (A/D) conversion process poses two primary challenges: one of quantization and one of sampling in time (Figure 1.3). Quantization refers to the uncertainty introduced upon conversion of an analog voltage to a digital number.

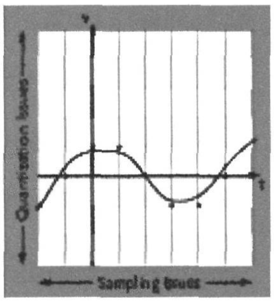

Figure1. 3 A/D conversion compromises

1.4 Sampling

Sampling is the process of taking a periodic sample of the waveform to be transmitted. If sufficient sample are sent, the waveform can be constructed at receiver. The more samples that are taken, the more final outcome looks like the original wave. However if fewer samples are taken, then other kinds information could be transmitted. The sampling theorem (Nyquist theorem) is used to determine minimum sampling rate for any signal so that the signal will be correctly restored at the receiver.

Nyquist sampling theorem states that, "The original information signal can be reconstructed at the receiver with minimal distortion if the sampling rate in the pulse modulation system is equal to or greater than twice the maximum information signal frequency". That is, sampling frequency,

$$f_s \geq 2f_{m(\max)} \quad [1]$$

Where; f_s = Sampling frequency

$f_{m(\max)}$ = maximum frequency of the modulating signal

The minimum sampling frequency;

$$f_{s(\min)} = 2f_{m(\max)} \quad [2]$$

Figure 1.4.1 shows the frequency spectrum of modulating waveform such as voice signal.

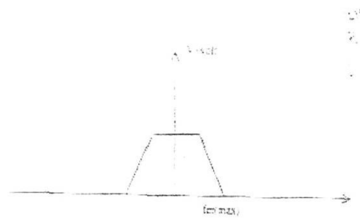

Figure 1.4.1 Frequency spectrum of a modulating signal

Three basic condition of sampling process are:

1) Sampling at $f_s = 2f_{m(\max)}$

When the modulating signal is sampled at a minimum sampling frequency, the frequency spectrum is shown in figure 1.4.2. In practice it is difficult to design a lowpass filter (LPS) which can pass only the highest modulating signal frequency, in order to restore the original modulating signal.

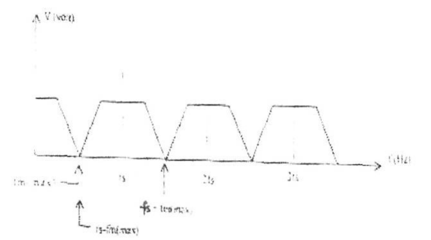

Figure 1.4.2 Frequency of modulating signal when sampled at $f_s = 2f_{m(\max)}$

2) Sampling at $f_s \rangle 2f_{m(\max)}$

This sampling rate creates a guard band between $f_{m(max)}$) and the lowest frequency component (f_s-$f_{m(max)}$)) of the sampling harmonics. Therefore a more practical LPS can be used to restore the modulating signal whereby can see in illustrate Figure 1.4.3.

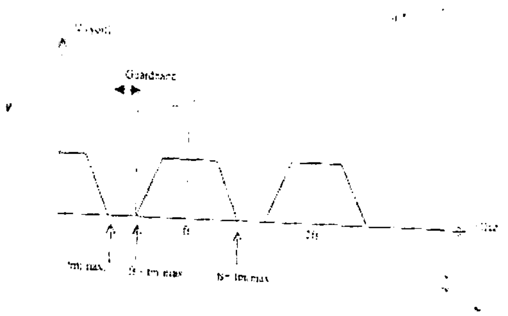

Figure 1.4.3 Frequency spectrum of modulating signal at $f_s \rangle 2f_{m(\max)}$

3) Sampling at $f_s \angle 2f_{m(\max)}$

When the sampling rate is less than the minimum value, this distortion is called aliasing or foldover distortion as figure 1.4.4

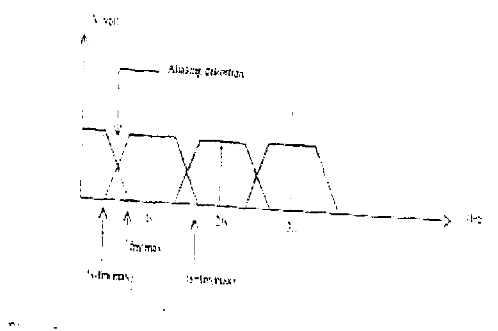

Figure 1.4.4 Frequency spectrum of modulating signal when sampled $f_s \angle 2f_{m(\max)}$

2.0 SCOPE OF WORK

The project focuses on two main areas that is the heart rate calculation and heart rate displayed using MATLAB software using graphical user interface (GUI) program. The normal analog pulse wave acquired using the developed the finger heart rate sensor monitor are saved using the digital oscilloscope. Then these data are loaded into the MATLAB for analysis and the estimated heart rate is displayed. Secondly an analog to digital (ADC) is also designed to obtain the digital output from the analog pulse. These ADC is meant for interface between the hardware with the computer. This part needs further improvement.

3.0 METHODOLOGY

This project consists of two main parts. Firstly the software development whereby the normal sample obtained from the developed finger heart rate sensor monitor hardware is saved and loaded into the MATLAB for analysis. The second part is design an ADC where the data obtained from the hardware would be digital output loaded into the computer that would be extended for future development.

3.1 Software Development

To implement the software development for this project MATLAB is used because MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm, development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building. In the MATLAB environment there are many toolboxes. For this project, MATLAB GUI is choosing because its user friendly characteristic and also because of it is suitable with Windows operating system. This system is said to be a user-friendly system because user can easily use this monitoring system without any complication in understanding its functions.

3.1.1 Heart rate determination

The program will determine the heart rate for that analog signal. The heart rate is the number of beat that produces by the heart in a minute. The calculation of the of the heart rate is shown in equation

$$HR = fs \times \left[\frac{60}{RR}\right] \qquad [3]$$

Where, HR is heart rate, fs is sampling rate of the signal and RR is the time delay between one amplitude to another amplitude.

3.2 Hardware Development

The aim of this digital circuit is to digitize the analog signal through a ADC0804 chip. The components are ADC0804 chip for quantization, 555 timer chip to obtain proper pulse for interrupt, L7805CV voltage regulator chip to get 5Volts from battery. ADC 0804 is chosen because it features the differential analog voltage input has good common-mode-rejection and permits offsetting the analog zero-input-voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full bits of resolution. The functions of the input and output signals are:

CS (Chip select) is selecting whether RD and WR to have any effect. This input must be in its LOW state. WR (write) is a LOW pulse is applied to this input to signal the start of a new conversion. It is called WRITE because typically the microcomputer generates a similar pulse to be used for writing to memory. RD (read) is a low pulse is applied to this input to enable the digital output buffers. The digital outputs pins will have logic levels representing the results of the last A/D conversion. It is called READ because the microcomputer can then read or fetch the digital data value over the system bus. INTR (interrupt) is end-of-conversion output signals which go LOW at the end of data conversion. It is called INTERRUPT because typically it will be sent to a microprocessor's interrupt input to let it know that the ADC data are ready to be read. VIN (-) allows the ADC to have differential inputs because the actual analog input, VIN, is the difference in the voltages applied to pins VIN (+) and VIN (-). In the single-ended measurements the analog input is applied to VIN (+), while VIN (-) is connected to analog ground.

4.0 IMPLEMENTATION

To implement the project for the software development this project is designed by using GUI program in MATLAB. This is a very user-friendly system for finger heart rate sensor monitor which the system will detect the cardiovascular pulse wave. The system was tested with the real data. The output of this monitoring system is shown in figure 4.1

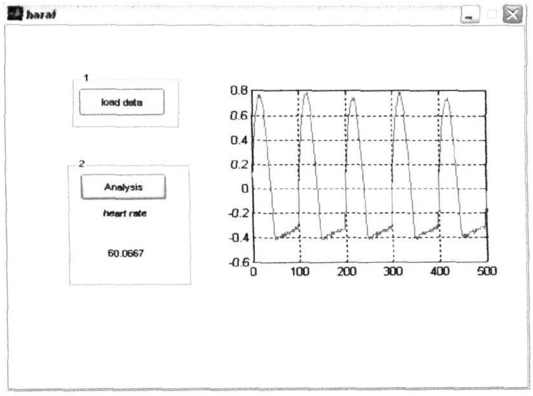

Figure 4.1 Output layout of this monitor

This system is said to be very user-friendly because user can interface this system with the DATA file in the text format from any directory such as hard disk, thumb drive and diskette. Figure 4.2 show data loading process.

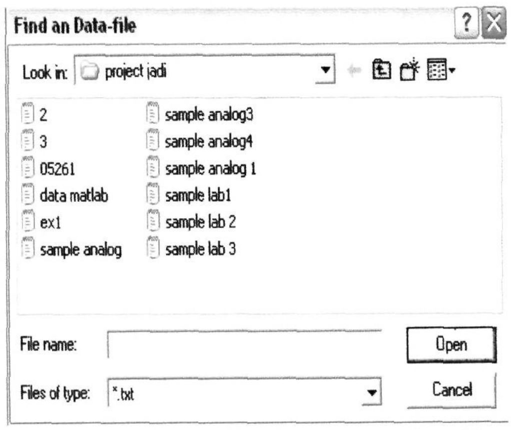

Figure 4.2 Data loading process for this system

The system will determine the heart rate and figure 4.3 below show the output for analysis

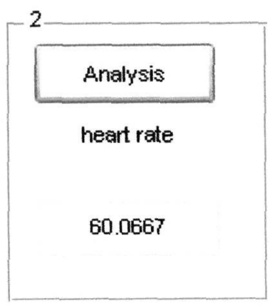

Figure 4.3 The output for analysis

5.0 RESULT AND DISCUSSION

For this chapter it consists of two main parts whereby the result is observed for analog signal and digital signal. The samples of data taken are real data.

5.1 ANALOG SIGNAL

The analog signal is captured from the finger heart rate sensor monitor developed from another project. The digital signal is acquired from the digital circuit that is developed for this project. The data acquired from both the analog and digital circuits are then saved using a digital oscilloscope. Then these data are loaded into the computer where MATLAB Mathematical software is used to analyze the captured signals. Figure 5.1, 5.2 and 5.3 below shows the data saved in oscilloscope.

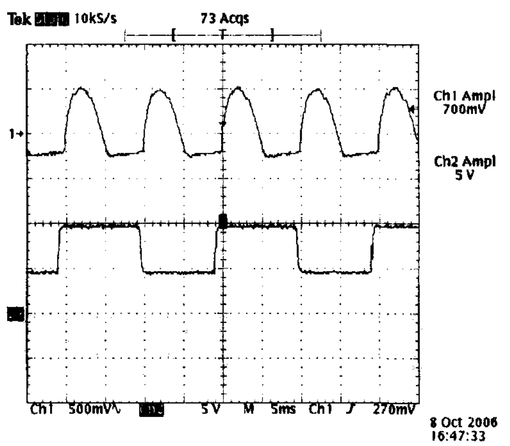

Figure 5.1: Output from the oscilloscope for sample 1

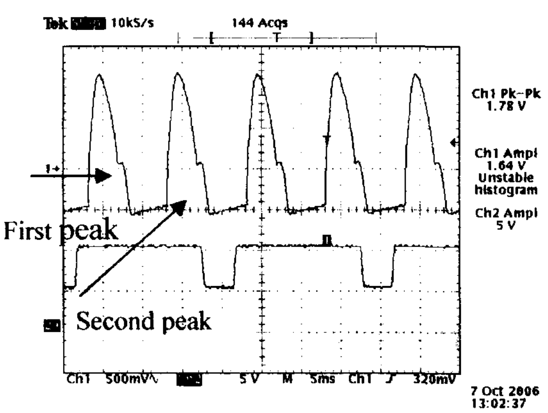

Figure 5.2: Output from the oscilloscope for sample 2

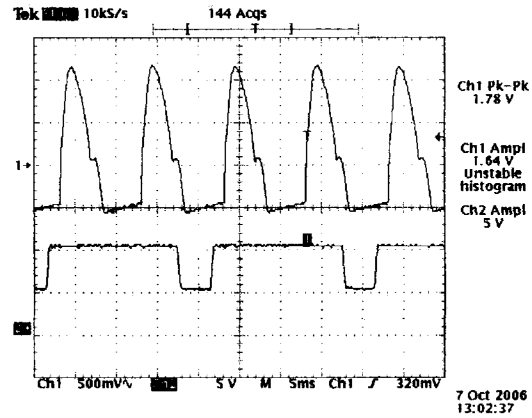

Figure 5.3: Output from the oscilloscope for sample 3

The above figures show the analog and digital output. The upper signal is analog signal acquired from finger heart rate sensor monitor where the estimated heart rate can be calculated. The second signal is the digital output taken from pin 18 of the ADC0804 chip.

From the figures displayed, it can be seen that the digital output does not represent exactly the analog output. There is a loss of signal where the second peak of the analog signal is not detected or sampled. This is because the signal frequency is around 100Hz and the sampling frequency used is also 100 Hz. To avoid the loss of information, the sampling frequency should be greater than or equal to twice the highest frequency of the analog signal according to Nyquist Theorem $f_s \geq 2 f_{m(\max)}$. Hence for this analog signal the sampling frequency should be greater than 200Hz.

Actually in this project the ADC can be designed using the sampling frequency of 100 Hz because the analog signal acquired from the finger heart rate sensor monitor should be around 1Hz to 1.5 Hz for normal heart condition .[3]. Since the hardware outputs an analog signal with frequency of around 100Hz for normal heart condition, the ADC cannot detect the second peak of the analog digital signal and an error is introduced in the figure. The calculated heart rate value is also 100 times the exact value of heart rate.

However the quantization circuit designed works well where the analog signal is quantized to give a digital output of 5V peak. The quantization is important to transmit the data. The more signal is quantize the data more accuracy. This is important when the data will to transmit in the computer. Based in figure 5.1, 5.2 and 5.3 the digital output is not satisfactorily sampled.

The calculation for the estimated heart rate for the sample 1:

Heart rate = 60 sec/ (2 x 5m) sec
= 6000 beat/second

The result show the estimated heart beat is 6000 beat per second. It shows that the estimated heart rate is wrong. For this reason in the MATLAB programming, the sampling rate frequency, fs is fixed to 100Hz so that the MATLAB programming doing analysis in correct answer. The estimated heart rate became bigger because the time delay between one amplitude to another amplitude very small (in mili second) whereas the time delay should be in second to get the correct answer. After the data saved from the oscilloscope loaded into MATLAB programming for analysis then the estimated heart rate will display by using GUI. The figure 5.4 below show the output after the data loaded into MATLAB programming.

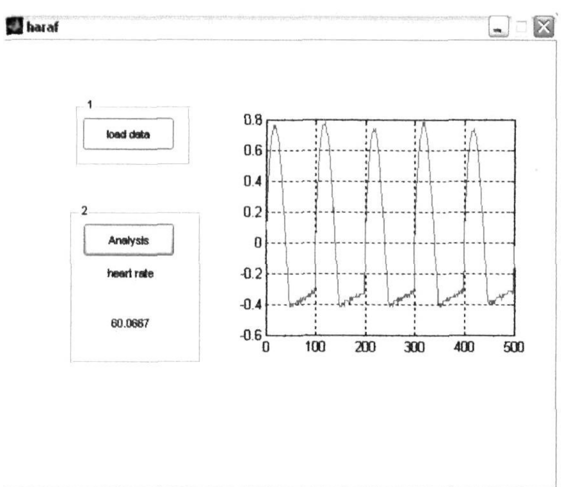

Figure 5.4: The output saved from oscilloscope analysis by MATLAB programming

For the heart rate calculation in MATLAB programming use the equation [3]

$$HR = fs \times \left[\frac{60}{RR} \right]$$

E.g.: Example calculation heart rate for MATLAB programming

 # the value RR gets from the MATLAB analysis when running the program according to figure 7.4

RR= 99.8889

Fs=100Hz

$$HR = fs \times \left[\frac{60}{RR} \right]$$

= 100 x 60/99.889

= 60.0667 beat/per second

The above result showed that the calculation of heart rate whereby when the sampling rate fixed to 100 Hz the MATLAB analysis can give the correct answer.

Table 5.1 shows the result of output finger heart rate sensor monitor that interface to this system. All the sample is get from the real data that saved by oscilloscope. This real data is observed using 3 different people.

Sample	Heart rate
1	60.0067
2	60.0067
3	60.000
4	60.0667
5	59.9334
6	60.2007
7	60.0667
8	53.2151
9	60.0000
10	60.2679
11	60.0000
12	60.1336

The results above show that the analysis by MATLAB programming is almost same between samples to another sample because the three people are in same age which 24 years old but in different weight, sex, and types of color of skin. The result shows that there some heart rate calculation is less than 60 beats/minute. If the calculated heart rate less than 60 beat/minute it shows that the heart rate term in bradycardia while the range 60 beats per minute is normal.

7.2 DIGITAL SIGNAL

For this part, the digital signal that saved in the oscilloscope, then loaded to the MATLAB programming just to display that the signal can converted the analog signal to digital signal. Hopefully that this project can be further extended. Figure 7.5 and 7.6 show the digital signal are display in the finger heart rate sensor monitor.

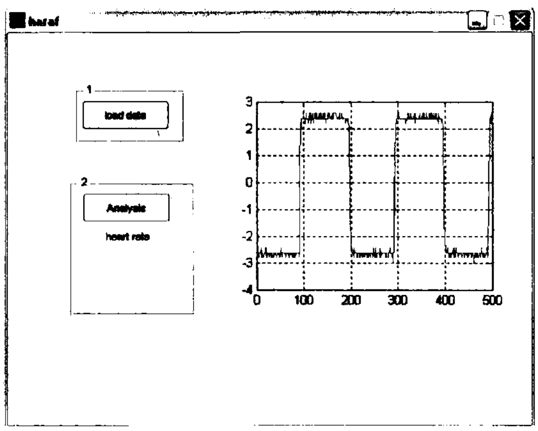

Figure 7.5 Output digital signal display in GUI for sample 1

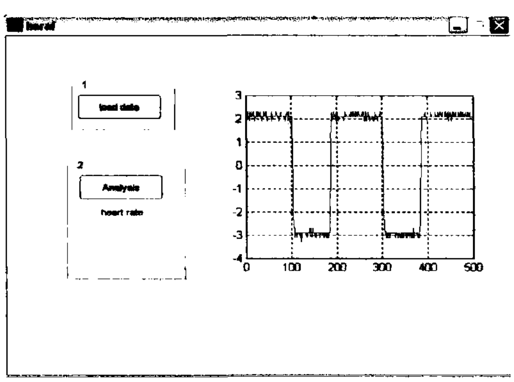

Figure 7.6 Output digital signal display in GUI for sample 2

6.0 CONCLUSION

This project achieves its objectives to monitor the finger heart rate sensor using graphical user interface (GUI) in MATLAB. The developed system is capable to calculate the heart rate for finger heart rate sensor monitor. However this system only can calculate the heart rate in correct answers if we fixed the sampling frequency 100 Hz. The reason why the frequency sampling is fixed 100Hz because the analog frequency that produce by the finger heart rate sensor hardware should be in 1Hz but the frequency that obtained from the hardware achieve at 100Hz so that it give some disadvantages of this system that need to improve. Beside that, these projects have done the design of analog to digital converter that produce the digital output, if the circuit can be modify so that it can be interface with computer in near future

7.0 FUTURE DEVELOPMENT

This project could be further extended in order it can interface with computer whereby real data can be analyzed directly. Likewise this project also can be extended by using wireless technology.

8.0 ACKNOWLEDGEMENT

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9.0 REFERENCES

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