ECG Noise Filtering Using FIR-Detection Algorithm On STM32F4 Board

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***Abstract*— This paper displays the implementation of ECG noise filtering method by using one of the simplest and lowest cost methods which is CMSIS-DSP on STM32F4 board and a FIR low pass filter as the embedded solution. The system improvised ECG reading and processing in the form of text files due to lack of proper ECG reading electrodes. Noisy ECG signal was generated and once uploaded into the board, was processed using Low Pass filter coefficients. High frequency noises were filtered from the ECG signal successfully.**

***Keywords*— ECG, CMSIS-DSP, Noise filter, Nucleo, STM32F4**

I. INTRODUCTION

Embedded systems are currently having an increasing market share due to their portable nature and moderate computing capability. In normal cases, an embedded system is required to respond to real time events according to its assigned functionality. For instance, a security alarm system has to respond upon detected suspicious movement, proceed to alerting regarding parties or feedback the visual information and more. If a task requires spontaneous computation of inputs, an embedded system is to be chosen to use in design.

In this project, our team has targeted to eliminate ECG signal noises by using FIR-detection algorithm and programmable board as the representation of embedded hardware. In short, an external SD memory card module is used to keep the converted ECG audio file in text format so that the Nucleo board is able to access the SD memory card thru a Serial Peripheral Interface (SPI) connection. After the data is being transmitted into the board, it will pass through the process of FIR and the output is transmitted back to the SD card. The input and output waveform of the audio can be observed through the serial monitor using the default Universal Asynchronous Receiver Transmitter (UART) interface.

II. PROBLEM BACKGROUND

The electrocardiogram (ECG) signal consists of vital data of cardiac activities in the form of an electric pulse. Such information can be used to diagnose any potential heart disease, and is prevented from being used without medical screening beforehand. This is because of the high sensitivity of the equipment that collects ECG signals, which may lead to misdiagnosis without checking patients for any cardiovascular disease symptoms.

Due to the monitoring purpose, a clean and stable ECG signal is usually demanded. Despite that, ECG signals are typically plagued with noises such as motion artifacts, baseline wander and power line and other device interferences. Motion artifacts and baseline wander could be minimized via constriction of patient movement and graphical calibration of the resulting ECG signal. Higher frequency interferences, however, could severely distort the signal and might render it unreadable.

Noisy ECG signals are unwanted as the diagnosis based on them has high error margin. Figure 1 shows a high frequency noise-induced ECG signal that belongs to a healthy heart, which is similar in terms of visual graph reading compared to an ECG from an atrial fibrillation patient. In cases of remote ECG monitoring, medical instructors cannot determine whether the patient is healthy or assaulted by atrial fibrillation with noisy ECG reports.

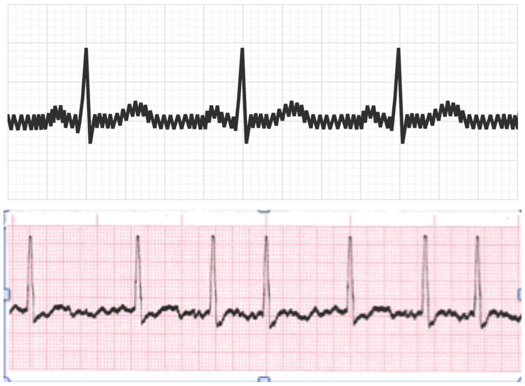

Figure 1: Similarity between power line interfered with normal ECG and atrial fibrillation ECG graphics.

III. CURRENT WORKS

Numerous attempts to filter the ECG signal noises have been made to this date, and were very successful in their respective aspects. Shirbani and Setarehdan (2013) [1] proposed a sophisticated ECG noise eliminator by utilizing fast fourier transform and adaptive algorithm. Shirbani worked on adapting time varying central frequency of high frequency interferences, for their case is the power line noise, using fast fourier transform to effectively filter out the floating electromagnetic field interference without attenuating the ECG information.

Zhou and Hou [3] did also propose an adaptive method to detect QRS waves among the ECG signal stream in order to enable quick and accurate automatic ECG diagnosis technique. The yield on their detection algorithm indicated sensitivity and specificity of >99%.

There are plenty of projects and patents regarding digital signal processing that could be referred to. But the complexity of these designs and hardware used are unfriendly for new learners. As a student, it is hard to obtain live ECG data to process with, due to the leads and ECG reading devices are hard to reach and require proper installation to use.

All these lead to the design of an embedded system to cancel ECG signal noise, especially high frequency, using an improvised yet powerful solution.

IV. METHODOLOGY

The design of our embedded ECG signal filter consists of three main parts, which are hardware, software and working algorithms. Hardware will be mentioning the microcontroller and development board chosen to realize portable and high computation speed of the design, and additional physical components necessary. Software is more of an improvised methodology to generate testing data (noisy ECG signal) and serial monitor feedback from the hardware system. The coding implementation of board initialization, noise filtering and wave-text file conversions functions that were coded into the development board.

A. Hardware

ECG signal is generated from a patient in real time manner, due to this a CPU with good real-time function and excels in digital signal processing was aimed for. ARM Cortex M series of processors is dedicated for embedded operations, emphasizing high performance and low cost and power consumption. STM32 family consists of development boards with a microcontroller of ARM Cortex M.

Within the programmable Nucleo board family, Nucleo-f446re with a price under RM100, but having an oscillation frequency of 32MHz and can be programmed using a wide range of integrated development environments (IDEs). STM32 Nucleo boards from F4 series are usually accessible to perform real time noise filtering methods. Therefore, STM32F4 board Nucleo-F446re is chosen.

Due to lack of medical instruments to record live ECG information, a dirty ECG signal stream has to be generated artificially. To transmit the signal from the simulation environment to the hardware, a micro SD memory card was utilized as a portable memory device. Converted text file consists of the artificial ECG information stored in the SD-card, which was connected to the SD card module (card reader) as a slave peripheral of the Nucleo board. The SPI1 port of the board was connected to the card reader, enabling read and write activities on the SD card. After filtering, processed ECG information was stored in the same SD card for displaying purposes.

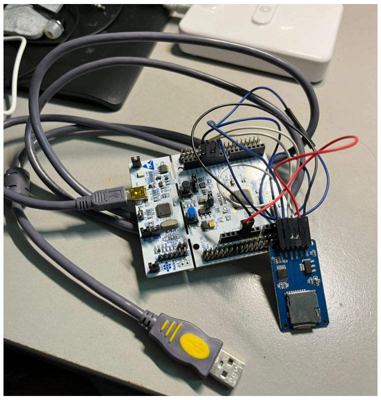

Figure 2: Hardware components after assembled.

B. Software

MATLAB and its tools were used in generating the noisy ECG signal Once a clean ECG signal can be successfully created the signal function was added with high frequency noise representing power line and electronic devices interferences. 20000 samples was generated as the continuous signal per shown in Figure 2, while a text file of exact samples was generated for data transmission.

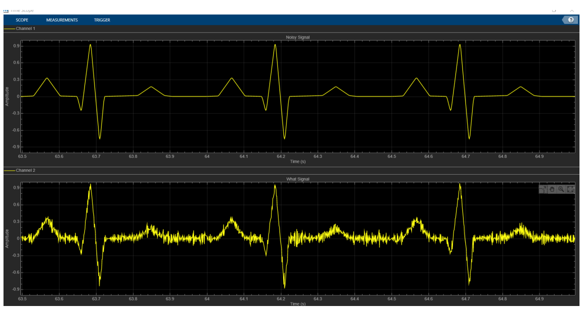

Figure 3: Clean ECG versus high frequency induced ECG.

Next, by using a MATLAB tool named Filter Designer, the coefficient of a filter could be extracted. To eliminate high frequency noise, a low pass filter was to be designed, with specifications listed below:

Sampling Frequency = 1000 Hz
Cut off Frequency = 400 Hz
FIR Window = Hamming, Window
Order = 20
Filter Type = Low Pass Filter

These specifications are entered into MATLAB Filter Designer to finalize a filter. After that, the filter coefficients were extracted and jotted for the FIR algorithm.

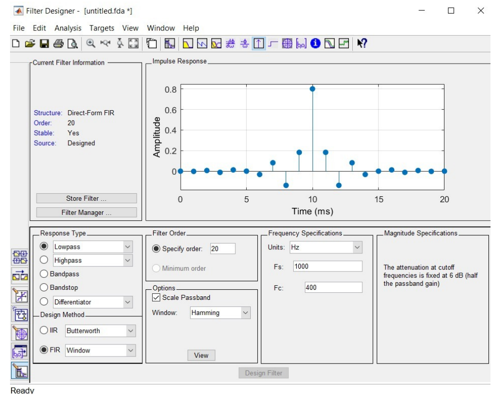

Figure 4: MATLAB Filter Designer used in low pass filter designing.

STM32CubeIDE was used to configure the hardware Nucleo board in C language. It is a peripheral configuration middleware for STM32 family and, if libraries are available, other chips. The Nucleo board was configured using STM32CubeIDE with board initialization and low pass filter functionality, debugged using the same IDE before running the serial reading of the noisy ECG signal text file from SD-card.

To program the Nucleo F446re which is an ARM Cortex based device, Common Microcontroller Software Interface Standard (CMSIS) library should be considered. It is a standard high-to-low level language interface for users to properly interact with ARM Cortex devices that contain peripherals from different vendors. Current project design used hardware abstraction layer (HAL) and CMSIS-DSP, a standard library under CMSIS that consists of wide mathematics, filtering functions and more. HAL in CMSIS-CORE allows users to initialize core accesses on STM32 boards such as I/O port, read or write, and clocks on separate ports. With CMSIS-DSP the team realized filter functions into Nucleo board within a short period.

In addition, during the ECG filtering and text file storing on the Nucleo board, PuTTY terminal was opened as a serial monitor to monitor the board from any errors and failures that stop the process.

C. Algorithm

Some coding along with the filtering algorithm are implemented into the Nucleo board. Starting with headers, several common headers such as string.h and stdio.h were included. In addition, FatFs module was sourced and included at the header area of the code. File allocation table filesystem (FatFs) module was utilized to tape in and out the ECG signal in text format to and from the SD memory card, which will be used in the main function.

After all the necessary headers were included, ports were initialized with functionalities such as general purpose I/Os for SPI interfaces (SCK, MISO & MOSI and CS ports) and UART connection.

Next, lines of prompts should be added per action within the main function loop to feedback basic messages from the board to serial monitor via UART connection. The filtering process could therefore be monitored.

Main function of the system, which was the algorithm implemented, is the signal processing loop. The loop consists of a low pass filter function with predefined coefficients (from MATLAB Filter Designer) and file reading/writing functions using sourced FatFs library.

One of the CMSIS-DSP functions: *arm_fir_init_f32* allows users to configure a filter without much trouble. The low pass filter is configured outside of the main loop. While there is still remaining ECG information, each row of ECG data was read into the function *arm_fir_f32* to be processed. Corresponding filtered signal outputs from the same DSP function were to be written to the SD memory card as a text file.

```
    arm_fir_instance_f32 S;
    …
    arm_fir_init_f32(&S, NUM_TAPS,
&firCoefficient, &firStateBuffer, blockSize);
    …
    [files opened, read one, write another]
    …
    while(file is not empty) {
      [read current row of ECG information text]
      arm_fir_f32(&S, read_data + (row_count*
blockSize),
      output_data + (row_count * blockSize),
blockSize);
      [write filtered data to output file]
      row_count++;
    }
    …
    [files closed]
```

Figure 5: Pseudocode of the main function.

The program reads the dirty ECG signal in text format from the SD memory card module via SPI and processes it to produce filtered instances of the ECG signal. These instances were stored back into SD memory as an output text file.

V. RESULTS & DISCUSSION

The signal processing was considered done as the finish message is shown on the serial monitor.

The filtering process was finished, the SD card was to be read at a PC and the output file was transferred into the PC. MATLAB was used in plotting the filtered ECG signal. Comparison was made between the dirty ECG signal and the filtered ECG signal.

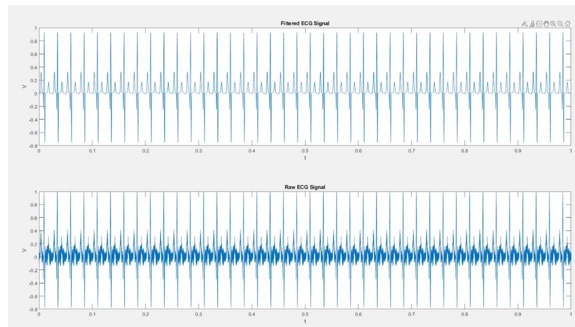

Figure 6: Filtered ECG signal versus dirty ECG signal.

High frequency (1kHz) induced ECG signal, shown as the lower section in Figure 6, is full of spikes that visually thicken the overall waveform. In some scenarios where the frequency induced is in a lower frequency domain, the corrupted ECG data may even resemble one of the cardiovascular diseases where the patient’s heart rate increases drastically such as atrial fibrillation. In that case, the cutoff frequency of the filter should be calibrated to a lower value, in between 2Hz (normal heart rate) and 4Hz (atrial fibrillation heart rate).

Demonstration video regarding the signal processing indicated that minutes were required in processing the signal data from dirty into filtered one. This is due to the serial messages taking time to be transmitted back to PuTTY via UART connector per action, meaning that for 20000 samples of ECG data there are 40000 messages to be transmitted (read & write actions). Next command runs only after the previous one with its status reporting message sent.

VI. CONCLUSION

The embedded design was considered a success as it reached the aim to realize a low pass filter using STM32 board. By utilizing the improvised methods to input and output ECG signals, the process has been shown to be capable of filtering the high frequency noises out from the original ECG data. Current design is, however, only as a representative of a filtering device for high frequency ECG noise. Whilst widening the scopes, a more sophisticated solution that is able to filter more noise range and is more adaptive from current design could be aimed as a future development.

VII. REFERENCES

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