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Review Article

Neural network based on Verilog HDL for fetal ECG extraction

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Abstract

This work proposes a method used to extract fetal ECG signal. Fetal ECG is used to detect the proper functioning of fetus during the time of labour which helps the clinicians to diagnose the wellbeing of the fetus. In this paper, we used Verilog HDL to design a neural network for extraction of FECG (fetal ECG) from MECG (maternal ECG). XYLINX 3S500 model was used to implement the proposed signal. Fetal ECG was efficiently extracted with the help of an FPGA (field-programmable gate array) kit implementing Verilog HDL software.
Keywords: Fetal ECG, Maternal ECG, Verilog HDL.

1. Introduction

Extraction of fetal ECG and fetal heart rate is essential to know the well being of the fetus. Over the last 30 years cardiotocography technique, which makes use of Doppler ultrasound has been used. Even though this technique is the most widely available technique for fetal analysis it contains only the analog and mechanical information about the signal, whereas, electrical signal in a digitized manner gives more information about the fetus. The electrical recording has the potential to provide accurate r-r intervals between the heartbeats of the fetus. These readings helps us in determining fetal hypoxia, fetal malposition etc. Thus extraction of fetal ECG from the abdomen of a pregnant woman helps in having a wide range of future research in the field of medicine as well as biomedical engineering.

The electrical signal which we get from the fetal heart is known as fetal ECG. These are obtained invasively by placing surface electrodes on the abdomen surface of pregnant women. The signals which are obtained contain both maternal as well as fetal ECG. Till now many methods have been proposed for the extraction of fetal ECG and many researches are going on day by day in improving the existing methodologies and algorithms. In the past, many methods have been addressed in the literature. In Khamene and Negahdaripour [1] a wavelet transform-based method to extract the fetal ECG from the composite abdominal signal was used. The system proposed in Matonia *et al* [2] was maternal electrocardiogram recognition and suppression relying on determination of template maternal PQRST complex and its subtraction during consecutive maternal cardiac cycles. In Michel *et al* [3] cyclostationarity based source separation technique was used for Fetal ECG extraction. A method employing neural network properties has been used in Hasan *et al* [4] and [5].

In Mamun *et al* [6] independent component analysis (ICA) was used. Even finite impulse response (FIR) neural network [6] and fuzzy logic system [7] has been employed to extract fetal ECG signal. In this paper, we proposed an artificial neural network system to extract FECG using the same FPGA kit. It was different from the existing methods in having the neural network established in Verilog HDL itself. The paper is organized in different sections. In section II significance of the fetal ECG was explained, followed by the explanation of neural network architecture in section III and FPGA architecture in section IV. Finally in section V Simulation, Results and Discussions were explained.

2. Significance of fetal ECG

Determining the fetal health is critical for avoiding risks during pregnancies. Even though if there are no identifiable risks there is a possibility of 100% births not to happen. In order to avoid this, electrical activity of the fetal heart is recorded. The recording of the fetal activity helps us in determining the fetal heart rate.

The main aim of determining the fetal ECG is to avoid intrauterine compromise or death of the fetus. FHR monitoring has been widely used for intrapartum and antepartum monitoring to assess the well-being of the fetus. The pattern of fetal ECG helps us in determining the accelerations and deceleration of fetal heart rate thereby helping us in determining asphyxia and whether the fetus is a reactive non stress test (NST) or non-reactive NST. The morphology of the fetal ECG wave is similar to that of an adult ECG wave.

The fetal ECG signal obtained from non-invasive techniques is less in magnitude and is weaker when compared to the maternal ECG wave. The maximum amplitude of the QRS wave in the maternal ECG is around 100 to 150 µV whereas for the fetus its around 60 µV. The abdominal electrocardiogram is obtained non-invasively by placing electrodes on the abdomen of a pregnant woman. Figure 1 shows the morphology of a normal fetal ECG wave.

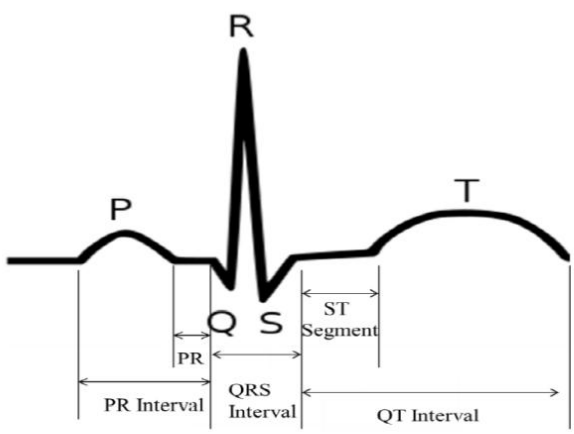

Figure 1: Morphology of a normal fetal ECG wave

3. Methodology

A. Design of Neural Network

The design of the neural network established here was that of an adaptive linear neural network filter and was designed to extract the fetal ECG from abdominal ECG of pregnant women containing both maternal ECG as well as fetal ECG.

The significance of an adaptive linear neural network filter is their ability to be used as an arbitrary function approximation mechanism or it learns from observed data which changes with respect to the situations. The linear network was designed in such a way that when there was a change in the input signal the linear network adjusts and was compared with the target signal to find the weights, thereby reducing the linear networks error due to the addition and squaring of the target and input signals.

The adaptive neural network used here was a combination of adaptive linear network and a tapped delay line network.

Here we made use of a feed forward propagation and an original fetal ECG as the target signal to train the neural network. The input abdominal signals were sent to enter through an array of N number of nodes having N-1 delays. Each nodal value was multiplied by weights and then they were passed through a summer followed by the linear transfer function. Figure 2 shows the neural network architecture.

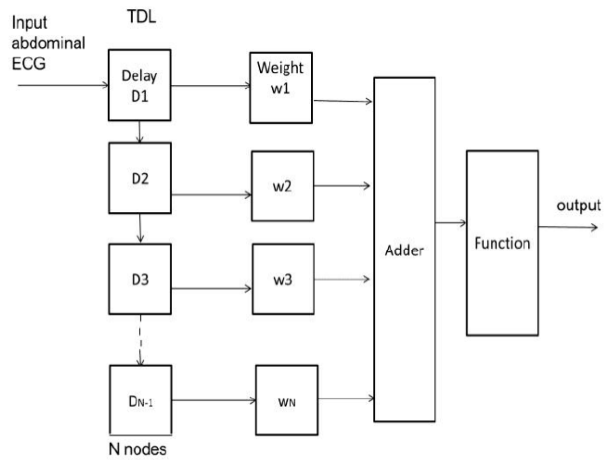

Figure 2: Neural Network Architecture

The values from the training vectors were given to the neural network and were compared with the target signal. With respect to the corresponding error the weight adjustments (Figure 3) were carried out. After the training was completed the neural network was loaded with the trained weight value to run in the real time.

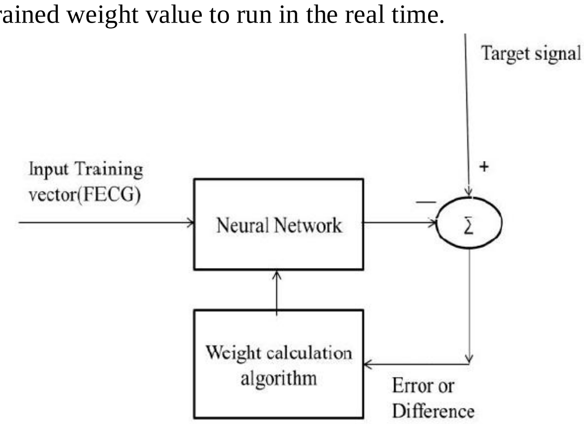

Figure 3: Weight adjustments

B. FPGA Architecture

The module was designed using Verilog HDL. In algorithmic level, the module was separated into two: weight adjustment module and extraction module.

Weight Adjustment Module

Here ASM (algorithmic state machine) chart was used to design the FPGA module. Figure 4 depicts the block diagram of the weight adjustment module.

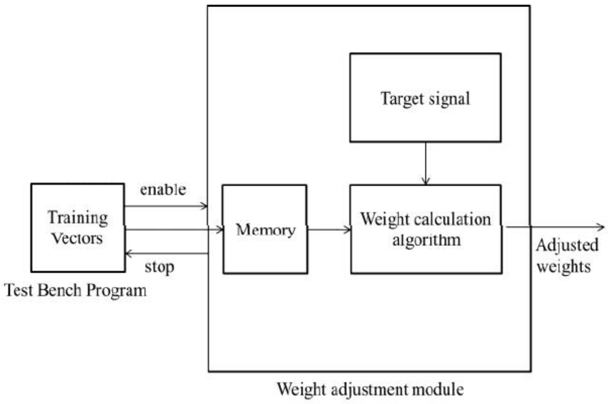

Figure 4: Weight adjustment module

Training vectors were given to the weight adjustment module using the test bench program. On receiving the training vectors the weights were adjusted according to the algorithm. The completion of iteration was sent to the test bench code. On receiving that signal, the test bench will send the next training vector. More than 50 training vectors (FECG signals) were used to train our neural network. We analyzed many number of FECG signal databases and obtained the vectors for training. Figure 5 shows some of the samples that were analyzed.

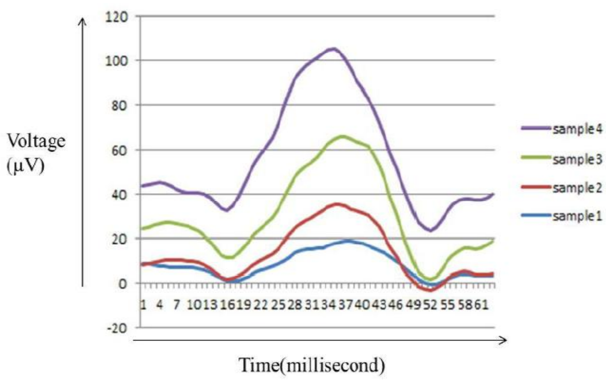

Figure 5: Training vector values

Extraction Module

The FPGA kit (XE3S500) receives the real time MECG signals serially and then stores it in „N" neural nodes. The neural network was designed with the trained weights that were obtained from the training module. At each and every cycle the FECG samples were sent to the FPGA kit using human user interface (visual basic program). The output of the neural network was analyzed at every second and if it was logic 1, the input signal arrived was a fetal ECG and was stored in the memory for further analysis. The same procedure was conducted to extract the fetal ECG from the remaining signals. All the extracted FECG signals were then analyzed for determining the wellbeing of the fetus. The pseudo ASM chart for extraction and analysis is given below in figure 6.

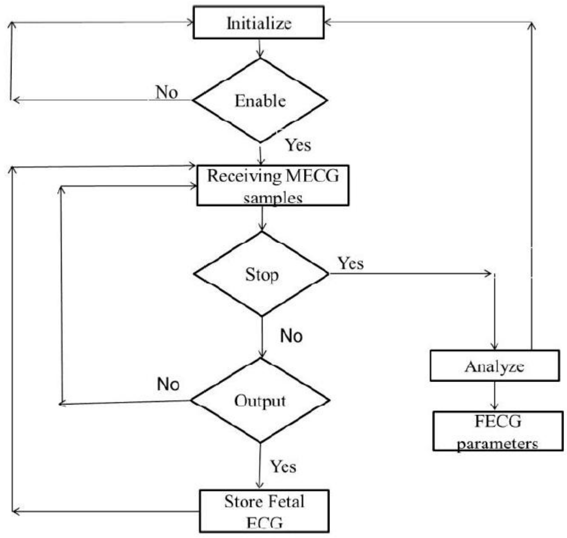

Figure 6: Pseudo ASM chart

4. Simulation, Results and Discussions

The Verilog HDL codes for ASM charts of different FPGA module and is simulated using Model Sim PE 5.5e software. Figure 7 represents the training vectors used to adjust the weights. These training vectors were chosen from the data base. 50 samples were used to train the neural network. The weight adjustment is shown in figure 8. These weights were used to run the extracting algorithm in real time.

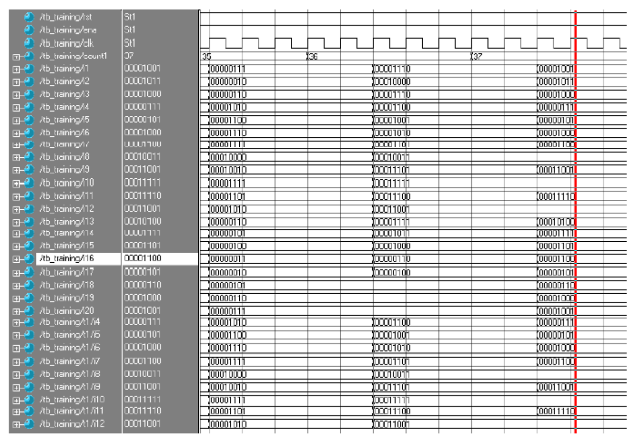

Figure 7: Training vectors used to adjust weights

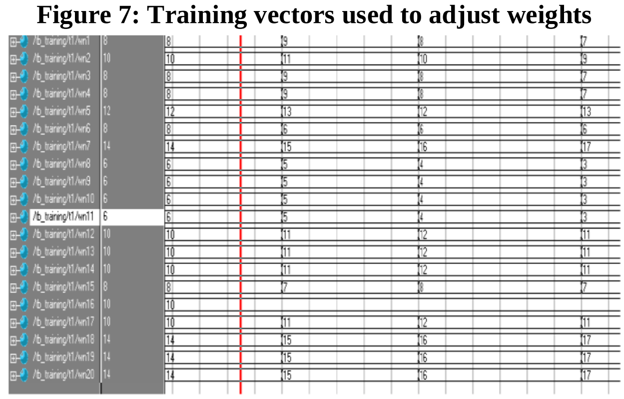

Figure 8: Weight adjustment

The successful extraction of the fetal signal and the logic 1 in "out "signal is represented in figure 9. The m0 to m1 represents the temporary memory for storing the extracted fetal signal. This data was used for analyzing the fetal signal. The figure 10 represents the graphical presentation of the extracted fetal data. Accurate fetal signal is obtained when the neural nodes get increased. The signal can be enhanced by increasing more neural nodes. The same steps were followed until it receives the stop signal. Therefore, at the end of the extraction, more of fetal ECGs is obtained for analysis.

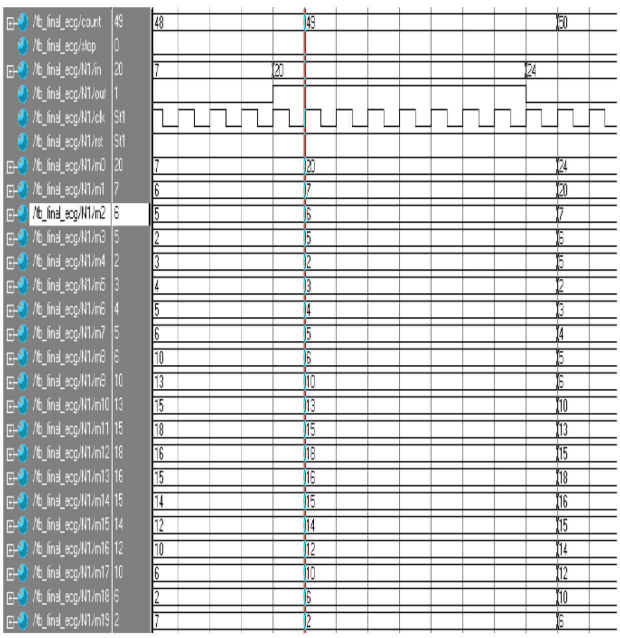

Figure 9: Fetal ECG signal extracted shown as logic 1.

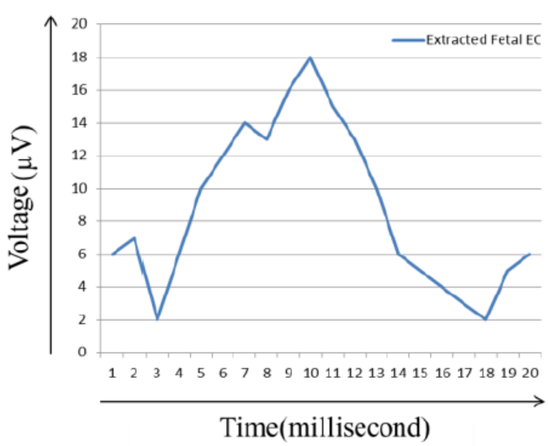

Figure 10: Extracted Fetal ECG

The extraction of fetal ECG using linear adaptive network has proved to be an effective and efficient method. Establishing the neural network in Verilog HDL proves to be more fast and efficient compared to the network established in Matlab and other platforms.

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