

SUBTRACTION PROCEDURE FOR TREMOR REMOVING FROM ECG: HIGH LEVEL SYNTHESIS WITH COMPAAN

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Резюме. Електрокардиограмата (ЕКГ) е често засегната от електромиографични (ЕМГ) смущения. Субтракционната процедура е доказала своята ефективност за премахване на ЕМГ от ЕКГ сигнали. Процесът на разработка на устройства, реализиращи подобни алгоритми за филтрация, често е труден и консумира много време. Синтезът на високо ниво решава тези проблеми. В настоящия доклад ние използваме инструменти за синтез на високо ниво, за да изработим устройство за отстраняване на ЕМГ смущения.

Ключови думи: ECG, Tremor, Compaan, HLS

INTRODUCTION

Electromyographic (EMG) interference is often present in the Electrocardiogram (ECG) due to involuntary muscle contractions of the patients (tremor). Suppression of such interference is very difficult because its spectrum overlaps the one of the useful signal. Subtraction procedure is proved to be efficient in tremor removing [1], [2], [3].

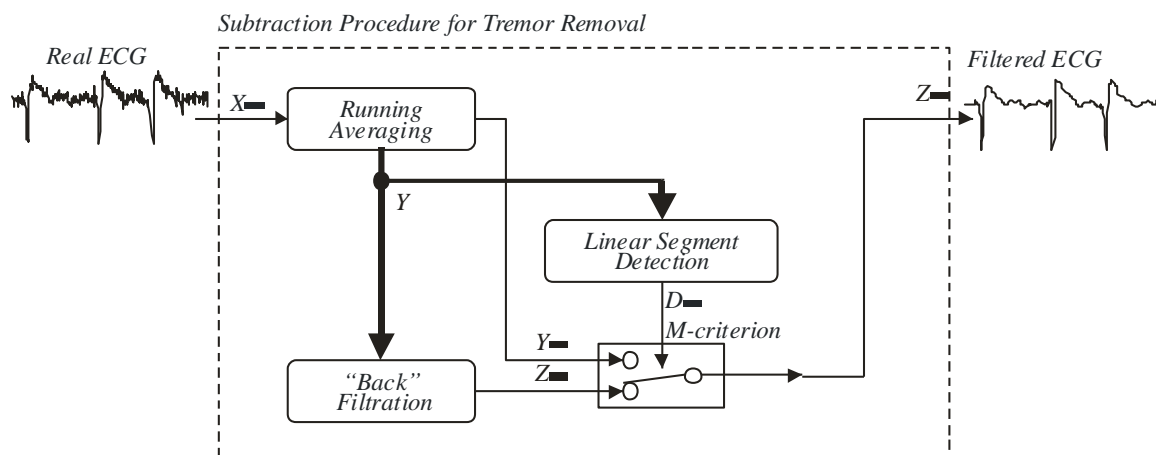


Fig. 1. Structure of the Subtraction Procedure for Tremor Removing from ECG.

The basic structure of the procedure is shown on fig. 1. The subtraction procedure algorithm is modeled in Matlab. Based on these algorithms is developed a hardware design for tremor removing form ECG [4]. This design realizes the subtraction procedure for real time operation. It is developed using VHDL and FPGA as a target platform. This standard manual development process using VHDL is error prone and time consuming. The design often must be reconfigured which is also a difficult process.

Several system level development technologies are presented in [6]. Automated high level system generation helps the development process and makes it easier and faster. In the present work we use Compaan to develop our design. Compaan is a high level synthesis tool [5]. Compaan provides full system integration implementing not only the hardware and software implementation but also the communication and integration between them.

SUBTRACTION PROCEDURE FOR TREMOR REMOVING

The subtraction procedure for tremor removing shown on fig. 1 consists of three basic stages:

- *Filtration of the signal* using running averaging for each input token;
- *Detection of linear segments*. Each filtered token from the ECG is defined whether it belongs to a linear segment using an appropriate linear criterion. The calculated linear criterion is compared with a predefined threshold M .
- *Back filtration*. If the segment is nonlinear back filtration stage is applied. The current value of the output token is restored using linear-angular interpolation of the signal in the segment.

More information about the subtraction procedure for tremor removing from ECG can be found in [1], [2], [3], [4]. The present paper is focused on the implementation of the tremor removing using the Compaan design flow.

COMPAAN DESIGN FLOW

Compaan design flow is centered on Compaan compiler and ESPAM tools [5]. Basic stages of the flow are shown on fig. 2.

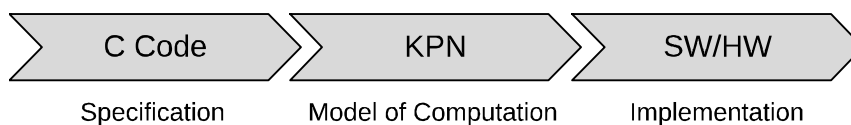


Fig. 2. Compaan Design Flow Basic Stages.

The input specification must be described as parameterized static affine nested loop which is a subset of the C language. Compaan compiler automatically generates a Khan Process Network (KPN) model of computation based on the input. Next step is to select a target platform and automatically map the resources onto it. HW is automatically generated by ESPAM based on the specifications. [5]

Nodes implemented with HW are using processors, which are composed of three separate blocks - read, execute and write. The read block waits until there are tokens ready to be read. A deep pipeline can be integrated in the execution block. Asynchronous work of the nodes and automatic links sizes optimizations make the design low power consuming. The high abstraction of the specification and the constant track of the data using counters make the design fault tolerant. [5]

IMPLEMENTING THE SUBTRACTION PROCEDURE FOR TREMOR REMOVING WITH COMPAAN

The basic structure and elements of the Subtraction Procedure for tremor removing are shown on fig. 1. We use the Compaan design flow which is shown on fig. 2 to implement the subtraction procedure for tremor removing. The following sections give detailed description for each step of the design flow.

Input Specification

As a first step of the development it is created the input SW specification. Short fraction of the C code input specification is presented to picture its main concepts:

```
#pragma compaan_procedure tremor
void filter(int data_in[WIDTH], int data_out[WIDTH], int
tremor_out[WIDTH], int cr_out[WIDTH]) {
    int ecg[WIDTH]; int cr[WIDTH];
    int ecg_linear[WIDTH]; int ecg_non_linear[WIDTH];
    int tremor[WIDTH]; int ecg_filtered[WIDTH];
    int filtered_signal[WIDTH]; int i, j, x;
    // Stream data into the design
    for (i = 1; i <= WIDTH; i = i + 1) {
        ecg[i] = data_in[i];
    }
    // Data processing
    for (j = 1; j <= WIDTH; j = j + 1) {
        // Signal filtration
        linear(ecg[j], &filtered_signal[j], &ecg_linear[j]);
        // Linear criterion calculation
        linearity_criterion(filtered_signal[j], &cr[j]);
        // Back filtration
        non_linear(filtered_signal[j], &ecg_non_linear[j]);
        // Switch signals based on the linearity criterion
        cr_switch(cr[j], ecg_linear[j], ecg_non_linear[j],
&ecg_filtered[j]);
        // Subtract the signals to define the filtered tremor
```

```

    subtract(ecg[j], ecg_filtered[j], &tremor[j]);
}
// Stream data out
for (x = 1; x <= WIDTH; x = x + 1) {
    data_out[x] = ecg_filtered[x];
    tremor_out[x] = tremor[x];
    cr_out[x] = cr[x];
}
}

```

Functions are called inside static affine nested loops to process the data. Inputs and outputs of the functions are given as parameters. Output parameters are specified as addresses to variables where the result is stored. Feedbacks from the output tremor to the linear and non-linear segment calculations are realized.

First step in the specification is to stream in data into the design. After the actual processing starts with the first block which is filtering the input signal. Linearity criterion is calculated based on the filtered signal. Another function implements the back filtration for the nonlinear segments. Nonlinear and linear outputs are switched based on the linearity criterion. The removed tremor interference is calculated by subtracting the original ECG signal and the filtered one. In the end the data is streamed out.

KPN Model of Computation

Compaan compiler is used to automatically generate KPN specification. This specification can be used as a basis to generate the actual implementation of the device. The KPN defines the dependencies between the nodes and connections between them.

The KPN is simulated to automatically optimize the communication link sizes. Fig. 3 shows the produced KPN for tremor removing from ECG using the Subtraction Procedure. Each function from the input specification is realized using a separate processing node. Additional processing nodes are used to stream data in and out from the design.

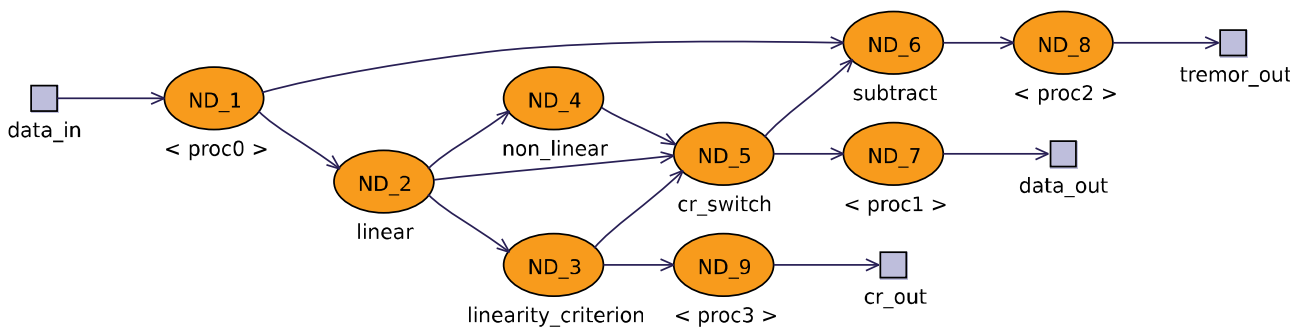


Fig. 3. Subtraction Procedure for Tremor Removing KPN.

Implementation

Next step of the Compaan design flow is selecting target platform and mapping creation. In our case we use default target and mappings, since we want to generate a project to simulate. After we have the KPN, platform and mapping specifications ready, we can generate synthesizable VHDL code. Each node is mapped to a hardware processing core. It consists of read, execute and write section. Each execution section must be additionally filled with the actual processing equations. The manually filled code realizes the relation between the inputs and the outputs in each block. An alternative in Compaan is to use third party tools to automatically generate the hardware logic. Also processor cores can be used to implement the processing algorithms.

At each step of the development flow we perform consistency check with the other stages to define if there are any errors. Thus errors are easy to be identified and fixed at earlier stages of the development.

EVALUATION AND RESULTS

Main target of our evaluation is to check if the generated design satisfies the application requirements. The development time is also a major aspect in this research. The system design must meet the functional and performance requirements and at the same time must be low power consuming and fault tolerant.

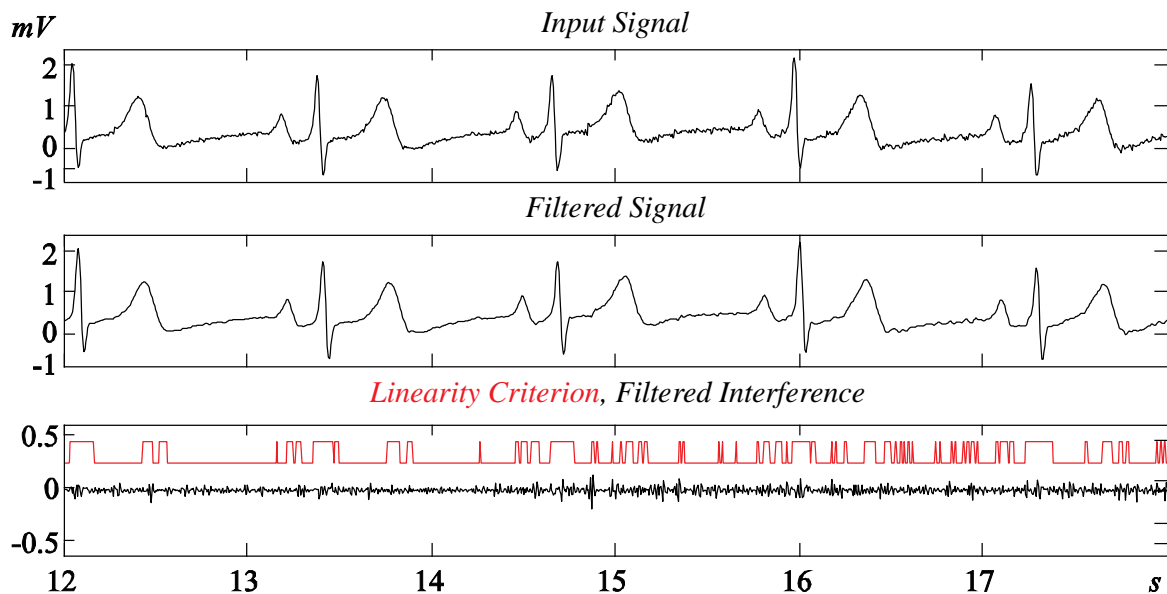


Fig. 4. Tremor Removing Result Signals.

We use Xilinx ISE Design Suite 14.7 to simulate and verify the design. Compaan automatically generates a test bench that streams in and out data from the

design. We use ECG signal provided by the American Health Association to test our design. Finally we use Matlab to plot the signals in graphics.

Fig. 4 shows result signals obtained by the simulation of the design: The results obtained prove that the integrated design realizes the subtraction procedure for tremor removing according to the modeled algorithms.

A manual VHDL implementation of the subtraction procedure for tremor removing is presented in [4]. In the current work we use Compaan design flow to develop the same tremor removing algorithm. The development using Compaan consumed 0,25 man-months and the manual VHDL development consumed 0,5 man-months. Using Compaan the development time required is considerably decreased.

The improvement in the development time is achieved thanks to the automation of the code generation and optimization. Using Compaan errors can be detected in earlier stages of the development. Hardware main structure and communication links are automatically created.

CONCLUSIONS

We use high level synthesis tool to develop a device that implements the subtraction procedure for tremor removing from ECG. Compaan design flow automatically generates an output design based on simple input specification. This considerably decreases the development time required. Compaan further optimizes the design and makes it fault tolerant and low power consuming. Quick changes in the specification can be made to generate a new design. This benefits any development and research process.

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