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Fpga Implementation Of A Marginalized Particle Filter For Delineation Of P And T Waves Of Ecg Signal

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ABSTRACT: The ECG signal provides important clinical information which could be used to pretend the diseases related with heart. So delineation of ECG signal is an important task. Whereas Delineation of P and T waves is a complex task.This paper deals with the Study of ECG signal and analysis of signal by means of Verilog Design of efficient Filters and MATLAB tool effectively. It includes generation & simulation of ECG signal, by means of real time ECG data, ECG signal filtering & processing by analysis of different algorithms & techniques. In this paper we design a basic particle filter which generates a dynamic model depending upon the present and past input samples and then produces the desired output .then the output will be processed by MATLAB environment to get the actual shape and accurate values of the ranges of P-wave and T-wave of ECG signal. In this paper Questasim a tool of mentor graphics is for simulation and functional verification. The same design is again verified using Xilinx ISE which will be also used for synthesis, mapping and bit file generation. Xilinx FPGA board will be used for implementation of system. The final results of FPGA shall be verified with ChipScope Pro where the output data can be observed.

Keywords: ECG, MATLAB, Bayesian filtering, particle filter, verilog hardware descriptive language.

I. INTRODUCTION

Many problems in science require estimation of the state of a system, a system using a sequence of noisy measurements produces changes over time. An ECG is a test that records the electrical activity of your heart through small electrode patches attached to the skin of your chest, arms and legs. So an ECG is generated by a nerve impulse stimulus to a heart. Heart pumps blood through the arteries and veins to organs, muscles and tissues, it works just as the central heating pump forces hot water through the pipes to radiators. Three distinct waves are produced during cardiac cycle, a P wave, a QRS complex and a T wave. [1]A typical ECG tracing of a normal heartbeat consists of a small U wave, normally visible in 50 to 75% of ECGs. P-wave caused by atrial depolarization, QRS complex caused by ventricular repolarization and T-wave, results from ventricular repolarization and relaxes. [5] The analysis of electrocardiograms (ECGs) has received increasing attention because of its vital role in many cardiac disease diagnoses. Most of the clinically useful information in ECGs can be obtained from the intervals, amplitudes, or wave morphology of the ECGs. Therefore, the development of efficient and strong methods for automatic ECG delineation is a subject of major importance.

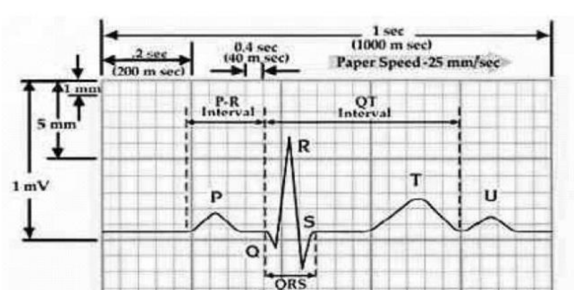

Fig 1 signal for one heart beat

The delineation of P-wave and T-wave is a challenging problem because of many reasons such as low slope and low magnitude, presence of noise, interference and baseline fluctuation, lack of delineation rules and waveform estimation technique. Baseline wander can be caused by: perspiration, respiration and/or body movements, two main approaches used are linear filtering and polynomial filtering. Other noise and interferences such as channel noise; muscle artifacts can be removed or reduced by using FFT, digital filters. There are many delineation approaches in the literature for P-wave and T-wave which can be classified as first class based on filtering techniques, a second class on the basis of expansion techniques, a third class depending on classification and pattern recognition method. [1] Delineation can also be based upon the concept of comparing a dynamic model to the ECG and generating parameters from the model to determine onsets and offsets of the waveform. P and T-wave delineation remains a complicated task, due to the low slope and low magnitude of P and T-wave and the lack of universally acknowledged clear rule to locate the beginning and the end of wave components. To analyze and make inference about a dynamic model, at least two models such as a model describing the evolution of the state with time and a model relating the noisy measurements to the state are required. We will assume that these models are available in a probabilistic form. In this paper, we introduce a novel Bayesian model that simultaneously solves the P- and T-wave delineation task and the point wise waveform-estimation problems. This model takes into account appropriate prior distributions for the unknown parameter (amplitudes). These prior distributions are combined with the likelihood of the observed data to provide the posterior distribution of the unknown parameter. Modern estimation theory can be found at the heart of many electronic signal processing systems designed to extract information. In determining good estimators the first step is to mathematically model the data. It is inconsistent to choose an estimator of unknown parameters that can result in values as expected. To incorporate this prior knowledge we can assume that A is no longer deterministic but is a random variable and assign it a pdf.

$$X[n] = A + w[n]$$

The parameter we are attempting to estimate is then viewed as a realization of the random variable Θ.

$$P(x, \Theta) = p(x/ \Theta). P (\Theta)$$

We begin in Section II with a description of the design flow. The Bayesian estimation and dynamic model generation is described in Section III. Section IV briefs about the computer tools required for design analysis and to simulate the processing module. The simulation details and results are explained in section V and section VI gives the conclusion.

II. DESIGN FLOW

(1) Ecg Data And X: The input signal is processed in MATLAB and divided into a set of samples x.
(2) Pre-Processing: the noise channels which get added along with data signal such as baseline wander, muscle artifact are reduced by using digital IIR filters and definition of search windows.
(3) QRS Complex Detection: since QRS Complex is the most characteristic wave in ECG signal, it is detected and the samples are counted before and after the R, which has the highest magnitude [3]. It is common to view ECGs as the union of two parts, namely, QRS-complexes and non-QRS regions. The interval between each successive pair of QRS-offset and the subsequent QRS-onset constitutes a non-QRS region.
(4) Estimation of the P and T-wave peak locations and amplitudes based on the generated samples. And P and T-wave detection and delineation based on the estimated P and T-wave peak.

Then these output samples will be processed in Matlab to generate the P-wave and T-wave's.

Stages of algorithm :

- ➔ Detection of R wave
- ➔ Estimation of start and end of ECG signal with respect to one heart beat.
- ➔ Finding count of all the waves and number of samples for each wave.

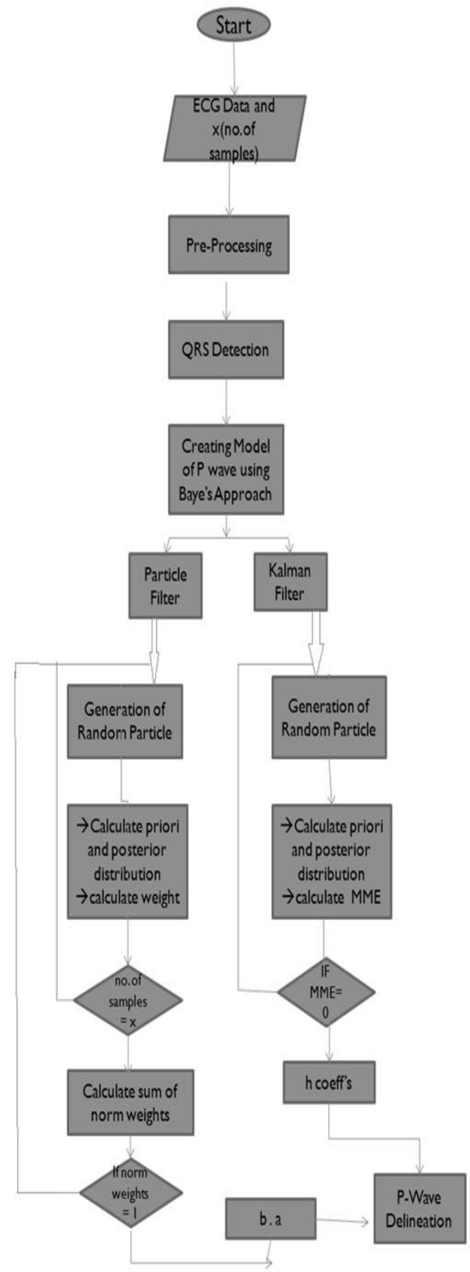

Fig 2 a *Flow Chart of Design Process*

- ➔ Evaluation of importance weight's and normalizing the weight's.
- ➔ Estimation of number of sample's and measurement update using Particle Filter.
- ➔ Generating dynamic model (proposal distribution) depending on measurement update.
- ➔ priori and posteriori estimations using Particle Filter time update and kalman filter measurement update.
- ➔ Differential convolution of dynamic model and input samples .

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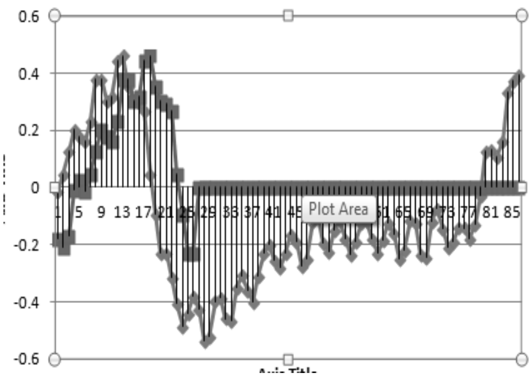

Fig.3 *convolution of dynamic and input signal*

III. BAYESIAN ESTIMATION AND DYNAMIC MODEL

Bayesian theory [4] was originally discovered by the British researcher Thomas Baye's. However, Bayesian theory has not gained its deserved attention in the early days until its modern form was rediscovered by the French mathematician Pierre- Simon de Laplace. Bayesian statistics to Statistical inference has become one of the important branches in statistics, and has been applied successfully in statistical decision, detection and estimation, pattern recognition, and machine learning. Monte Carlo technique [4] is a kind of stochastic sampling approach aiming to tackle the complex systems which are analytically intractable. The power of Monte Carlo methods is that they can attack the difficult numerical integration problems. One of the attractive merits of sequential Monte Carlo approaches lies in the fact that they allow on-line estimation by combining the powerful Monte Carlo sampling methods with Bayesian inference, at an expense of reasonable computational cost. In particular, the sequential Monte Carlo approach has been used in parameter estimation and state estimation, for the latter of which it is sometimes called particle filter. The basic idea of particle filter is to use a number of independent random variables called particles, sampled directly from the state space, to represent the posterior probability, and update the posterior by involving the new observations; the "particle System" is properly located, weighted, and propagated recursively according to the Bayesian rule.

P and T-wave detection and delineation criteria

P and T-wave detection and delineation are based on the estimated posterior distributions of wave indicators, wave amplitudes and waveform coefficients. These estimated posteriors are computed from histograms of the samples generated by the PCGS.

P and T-wave detection*:* Unlike most of the approaches found in the literature, no rigid amplitude threshold is used to determine whether waves are significant or not. The posterior distribution of wave indicators carries information regarding the probability of having a P or T-wave at a given location. Thus the detection results can be obtained with various degrees of certainty by using a local maximum posterior strategy. Since there can only be one Twave (P-wave) in each T-searching Neighbourhood (P searching neighbourhood), the proposed algorithm compares the highest estimated posterior probability in each neighbourhood with a given probability threshold (P for P-wave and T for T-wave) to decide whether it is significant or not.

Estimation of wave amplitudes and waveforms: For estimating the wave amplitudes AK corresponding to position k where a P or T-wave has been detected we use the evaluated weights and dynamic model. For waveform generation after detection of P and T ranges the samples (particles) along with peak locations and estimated offsets and onsets are measured using the combination of Particle Filter and Kalman Filter.

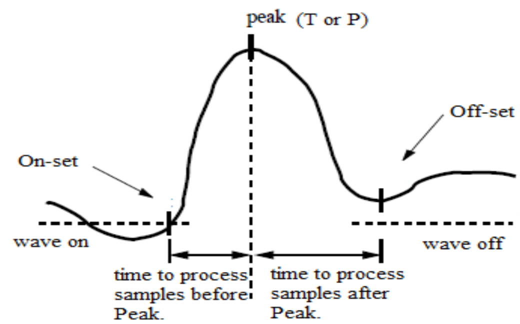

Fig.4. *Estimated on-set & off-set of P/T waves*

Delineation of P and T-wave: Since the estimated waveform carries information regarding the wave morphology, we propose a delineation criterion which is based on the waveform estimate of each processing window. First of all, the onset and end of wave are determined by applying two criteria: **i)** searching for the sample where amplitude is below a threshold (P_{on} and P_{off} for P waves, T_{on} and T_{off} for T waves) proportional to the maximum amplitude. ii) Searching for a local minimum of sample before or after the wave peak. The samples that satisfy either of these two criteria are accepted as candidates. Moreover, since all values of the estimated waveform located on the right of peak are above the threshold, end has been estimated as the first local minimum on the right of this peak. As there is no universally acknowledged clear rule to locate onsets and ends of waves, the delineation thresholds have been obtained by minimizing the error between estimates and published annotations.

Overview of Algorithm for the marginalized particle filter

Step-1: instantiation for I = 0, 1, 2…..N
$X^{N,I}$ → Input Samples.

Step-2: (1) evaluate importance weights
$\mathbf{q^{(i)}_t = p(y_{tj\,|}\, X_t^{p,(i)t}, Y_{t-1})}$ and
(2) Normalize
$$\mathbf{q'(i)t = q(i)t} \,/\, \textstyle\sum_{i=0}^{N} \mathbf{q(i)t}$$

Step-3: Particle Filter measurement update:
(1) Resample N particles.
(2) Calculation of $\mathbf{N_{eff}}$.

(3) Calculation of $\mathbf{Z_k}$.

Step-4: Generating Dynamic Model depending measurement (Z_k).Drawing a model of P-wave & T-wave using Baye's approach.

$$\mathbf{X_k = F_{k-1} * (Xk_{-1}, V_{k-1})}$$

Step-5: Particle filter time update and Kalman filter
a) Kalman Filter measurements update (Linear):

b) Particle Filter time update (Nonlinear):
(1) Priori estimation (X (k/k-1)) from dynamic model.
(2) Posterior estimation from Kalman filters time update.
X (K/k) = X (K/k-1) + K (k)*(diff)
(3) K (k) is Kalman gain. Finding position of particles along with amplitude and total number of samples in output signal.

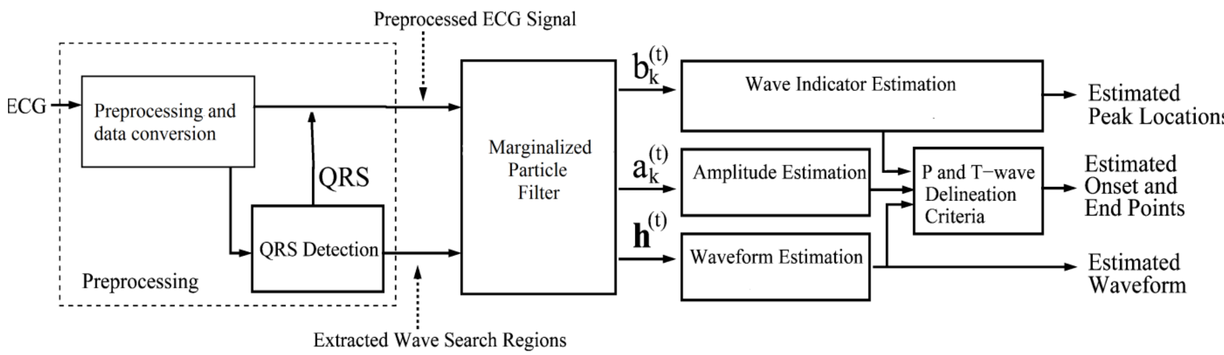

Fig.5. *General block diagram for the proposed P- and T-wave delineation algorithm*.

IV. SYSTEM TOOLS AND SIMULATION

Perl scripting language: PERL is a powerful scripting language, very popular among UNIX/Linux admins. We use perl to convert the input sample data from fractional decimal to hexa-decimal value.

Verilog Hardware Description Language: It is most commonly used in the design and verification of digital circuits at the register-transfer level of abstraction. It is also used to verify of analog circuits and mixed-signal circuits. The complete project is designed using Verilog HDL language.

Cadence Digital Design Tool: the Cadence System Development Suite allows software developers to run and debug their designs on top of a set of open, connected, and scalable platforms. We used Cadence in order to have a compatible atmosphere related to extract input data.

Matlab: Matlab allows matrix manipulations, implementation of algorithms, creation of user interfaces, plotting of functions & data, and interfacing with programs written in other languages, including C, C++, Java and FORTRAN. We have used Matlab to generate the ECG signal before and after the detection of P and T waves and to compare them.

Simulation tools for analog mixed-signal design: Questasim is a Simulator with additional Debug capabilities targeted at complex FPGA's and as well as SoC's. Questasim can be used by users who have experience with Modelsim as it shares most of the common debug features and capabilities. We have designed a Marginalized particle filter first in the Questasim environment, in-order to ease the process and make the design verified by supplying the test-bench.

Xilinx Synthesis Technology (XST): it is a Xilinx application that synthesizes Hardware Description Language (HDL) designs to create Xilinx specific netlist files called NGC files. The NGC file is a netlist that contains both logical design data and constraints. XST performs the following steps during FPGA synthesis and optimization:

- Mapping and optimization on an entity by entity or module by module basis
- Global optimization on the complete design. The output is an NGC file.

RTL Schematic of module for R peak search:

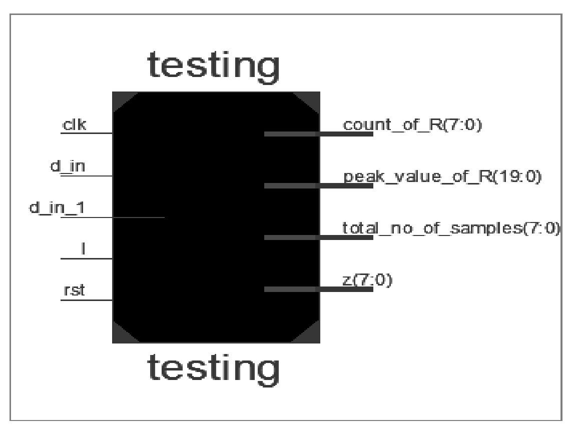

Fig.6*.RTL of R-peak search block along with evaluation of start and end of ECG signal*

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Fig. 7.*Simulation Waveform of R-peak detection along with computation of start and end of ECG signal.*

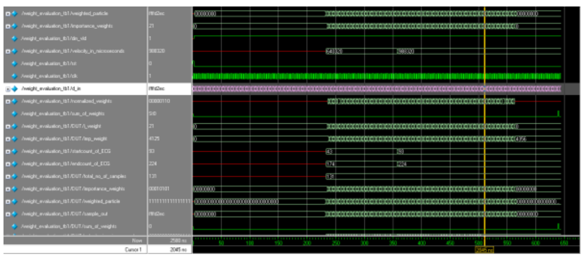

Fig. 8.*Simulation Waveform of weight evaluation of samples along with normalization and a signal showing sum_of_weights*

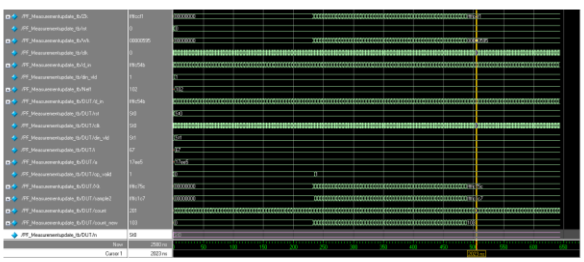

Fig. 9.*Simulation Waveform of Particle Filter measurement update showing Neff and calculation of Zk*

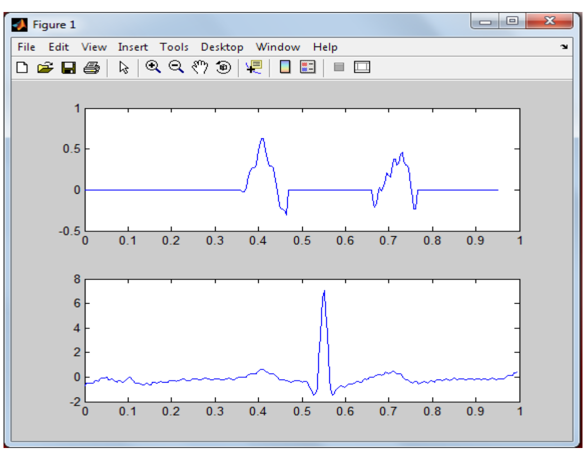

Fig. 10.*matlab Waveform of ECG signal before and after the filtration process*

Simulations were conducted to validate the proposed algorithm. First, we show some

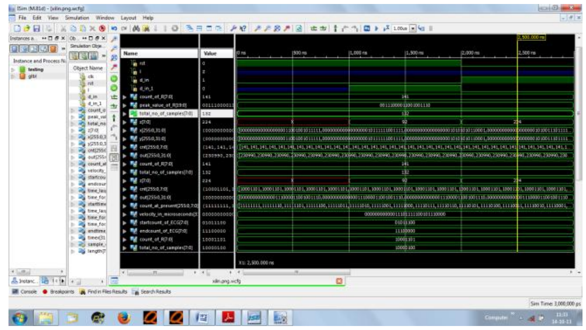

Fig. 11.*output in Xilinx xst using isim*

Posterior distributions and estimation results for one typical example. Then, graphical evaluations and analytical results on an entire database are provided. Usually, the validation of the ECG wave detector or delineator is done using a manually annotated database. This database was developed with the purpose of providing a wave-limit validation reference. The sequential importance sampling (SIS) algorithm is a Monte Carlo (MC) method that forms the basis for most sequential MC filters developed over the past decades. The key idea is to represent the required posterior density function by a set of random samples with associated weights and to compute estimates based on these samples and weights. The main part of the method by which the effects of degeneracy can be reduced is to use resampling whenever a significant degeneracy is observed (i.e., when falls below some threshold). The basic idea of resampling is to eliminate particles that have small weights and to concentrate on particles with large weights. One way to reduce errors might be that the proposed particle positions are chosen badly. One might therefore think that choosing the proposed particles in a more intelligent manner would yield better results. Once we have obtained the P- and T-wave locations, the corresponding wave amplitudes can be estimated by using marginalized particle filter. The estimated P- and T-waveforms determined using MPF is presented in Fig.10. The proposed method estimates the P- and T-waveform shapes pointwise for each processing window. Therefore, it can adapt to various wave morphologies.

V. CONCLUSION

Instead of deploying rigid detection and delineation criteria for all ECG time series, we used a local detection strategy and flexible delineation criteria based on the estimation of P- and T waveforms in consecutive beat-processing windows. The main contributions of the paper are as follows.

1) The introduction to a hierarchical Bayesian model for P and T-wave delineation.
2) The method proposed here, allows for the simultaneous estimation of the P- and as well as T-wave fiducial points and the P- and T-waveforms, which is rarely done by other ECG delineation methods.

The most significant improvement was found in the P- and T-wave detection rate and the positive predictivity. In addition, the proposed method can provide accurate waveform estimation. Note that the proposed method

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focuses on P- and T-wave analysis. Thus, deviations of QRS locations are not considered here. Note also that due to its sequential nature, the proposed one might have problems to handle signals containing several P- or T waves in the same research region, it is observed for atrial fibrillation.

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