A LOW COMPLEXITY HIGH SPEED ARCHITECTURE DESIGN METHODOLOGY FOR REDUCED 3-LEAD TO 12-LEAD ECG SIGNAL RECONSTRUCTION TARGETING REMOTE HEALTH CARE

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This Thesis entitled A low complexity high speed architecture design methodology for reduced 3-lead to 12-lead ECG signal reconstruction targeting remote healthcare by Utkalika Panda. is approved for the degree of Master of Technology from IIT Hyderabad.

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Dedication

To

My Parents

Abstract

Cardiovascular diseases is one of the prime causes of human corporeality and mobidity in society . In order to abate this researchers had paid heed in the field of detection and prevention in both hospital-based and remotely accessed environments . Advancements in wireless technology and tale-monitoring can be used to provide the accessibility of state-of -the-art(Sot A) facilities to patients in remote and rural areas. However, bandwidth and storage limitations and data transmission time are major challenges in wireless transmission . Though cardiologists are habituated to standard 12-lead (S12) system because of its decade old usage and widespread acceptability, however generally, for such remote healthcare environments a reduced lead(RL)ECG is suitable for aforementioned reasons , which however , may not be clinically acceptable for diagnosis . Several efficient algorithms for reconstruction of RL to SotA 12 lead have been proposed. The overall Cardio Vascular Disease detection system can be characterized to 6 different sections namely Data Acquisition , Preprocessing , Data Transmission, Coefficient Generation, Signal Reconstruction and Display on Monitor. The thesis work includes a low complexity and high speed architecture design (for the preprocessing section) and its implementation on FPGA and ASIC platform which intern can be used for the accurate reconstruction of 3 lead to 12 lead ECG signal reconstruction . The application of this architecture focused on remote cardiovascular monitoring, where continuous sensing and processing takes place in low-power, computationally constrained devices, thus the power consumption and complexity of the processing architecture to implement the algorithm should remain at a minimum level. Under this context, we choose to employ the discrete wavelet transform (DWT) with the Symmlet function being the mother wavelet, as our principal analysis method. The thesis exploit the research for reduced 3 lead to 12 lead reconstruction methodology and highlights the associated technical challenges while implementing the architecture and propose a low complexity, high speed architecture for computational intensive wavelet analysis.

Contents

1. INTRODUCTION

1.1 Introduction

Cardio Vascular Disease (CVD) is one of the prime cause of increase in human mortality rate , according to the World Health Organization (WHO) [1] , which has become a serious challenge to the world health management system. Hence increase in quality of healthcare with minimal cost is necessary in order to mitigate this inevitable situation. Pervasive health care through continuous health monitoring of disease prone physiological signals , for the patients affected by CVD can tremendously decrease the hospitalization and death toll rate .Commercialization of health care products are being done keeping an eye on pervasiveness of the health care system [2].

Advancement in wireless technology and internet of things can be harnessed for continuous monitoring of patients allowing them to stay at their own turf. This can be achieved by using a no. of wireless sensors and transmit the acquired signals to the health care center for further analysis and disease reorganization .These sensors are meant for capturing the vital physiological signals and are generally powered by battery system.

1.2 Research Challenges and Motivation

The traditional clinical feature extraction algorithms and information fusion techniques are very computational intensive tasks, hence are being executed by mainframe computational facilities. However, in such systems significant energy consuming component is the energy required by the radio front end for supporting continuous data transmission, which intern prevent a long-term sustainable operation especially in the remote areas. Implementation of such remote health monitoring system in rural and remote areas to take care large number of patients has two major bottleneck: first, bandwidth limitations , memory requirement and data transmission time [2]-[4] and second, cardiologists generally want to check standard 12-lead (S12) system, due to its widespread acceptability and usage over decades because at times other reduced lead (RL) systems are inadequate or insufficient for diagnosis and disease prognosis. Use of reduced lead(RL) system essentially with 3-4 leads can be a possible solution for meeting the technological limitation ,where unlike 8 signals of S12 system 3 or 4 number of signals need to be transferred to the health care centre. However, from medical perspective a RL system may not carry adequate information for diagnosis [5].

1.3 Vision

An ostensibly possible solution to the highlighted issues is to obtain S12 system from RL system which can be performed using lead reconstruction. Lead reconstruction methodologies have mostly been inspected in order to address the problems faced by patients and caregivers in a hospital based environments [6]-[13], however, they have been evaluated in the context of remote health monitoring application. One of the best among various lead reconstruction algorithms is reduced 3 lead(consisting of leads I, II and one of the six precordial leads) to SotA 12 lead signal reconstruction with the preprocessing module[14] for artifact exclusion. A patient needs to be registered to a nearby healthcare center which maintains a database to keep track of each patient’s health. During the registration process patients ECG signal is acquired using SotA ECG machine and transformation coefficients are generated which are stored patients respective data depository. Then after using personalized reconstruction methodology S12 system is reconstructed from the RL system , which is being transmitted to the health center, whenever the patient is need to be monitored. After reconstruction, signals can be displayed on cardiologists mobile phone/Tablet for further analysis and diagnosis.

1.4 Contribution of Thesis

Though rapid development in embedded technology, wireless technology allows to turn the algorithmic research into practical possibility, still there is huge gap between algorithm and architecture in the context of remote health monitoring scenario , where power consumption is the main constraint .To bridge the gap between the algorithm and remote health care system, in paper we propose a very low complexity and less power consumed architecture for the preprocessing module of CVD detection system, which will open up a significant opportunity in the rural health monitoring system development and will help making the concept of personalized healthcare in remote area a reality. To the best of our knowledge, this is the first work which led a path for realization of algorithm into a reality and intern can be able to lay a foundation of replacing the decade old bulky, costly state of art ECG machine with a tiny affordable product as a solution, keeping in mind various constraints related to rural health care environment .

2. PROPOSED ARCHITECTURE

2.1 BACKGROUND

There has been several research in the field of reduced lead system pertaining to the health care management sys-tem particularly for rural area because of inconvenience of patients with SotA ECG, technological challenges like limited power, memory and bandwidth However, according to cardiologist reduced lead system does not carry sufficient information .Hence, the thrust for reconstruction from RL system to SotA 12-lead system come up, where researcher tried to have a intermediate solution in both the context. In our previous work we developed a reduced 3- lead (R3L) system consisting of leads I, II and one of the six precordial leads with a preprocessing module[14], for personalized health care system to reconstruct R3L to S12 system, for giving an accurate and reliable reconstruction methodology than the earlier work. This is the first work to the best of our knowledge, for implementation of R3L to S12 system i.e algorithm’s implementation towards its realization for the improvement of rural health care system. Here in this paper we are proposing an efficient low complex, low power consumed architecture. This is the first work of its kind, where our architecture mainly focuses on the computational intensive ,power consuming part of CVD detection i.e the preprocessing module in the context of hardware software co-optimization. We compared the signal reconstructed from architecture and the signal reconstructed from algorithm with the corresponding original signal, by using R2 statistics, correlation (rx) and regression (bx) coefficients.

2.2 Material

PTBDB is a 290 patients 15 lead database with both S12 and FV system simultaneously acquired and digitized at the sampling frequency of 1 kHz. The patients in PTBDB were categorized on the basis of their cardiologic disorders such as bundle branch block (BB), healthy control, hypertrophy, cardiomyopathy and heart failure, myocardial infarction, valvular myocarditis and other miscellaneous. The raw signal was then preprocessed for removal of BW and noise. Out of 290 patients 101were used for verification of the proposed architecture and rest were excluded from the study pertaining to their extreme artifacts and paced rhythm.. The diseases categories and their numbers used for testing includes bundle branch block (BB -14), healthy control (HC-20), hypertrophy, cardiomyopathy and heart failure (HY - 10), myocardial infarction (MI - 30), valvular myocarditis and other miscellaneous (VA-27).

2.3 Mother Wavelet – Symmlet with DWT

The algorithm for already proposed and verified preprocessing module comprises of baseline wandering (BW) removal based on discrete wavelet transform (DWT) [17] and de noising based on translation invariant wavelet transform (TIWT) [18]. In this project because of hardware perspective, only DWT has been considered for wavelet transform .The number of input samples be as the power of 2 for the implementation of DWT and TIWT. For example, if a patient’s ECG is recorded for about 38s the number of samples obtained at a sampling rate of 1 kHz was 38000, out of these algorithm had taken 2^15 = 32768 samples i.e. first 32768 samples for the algorithmic need and rest has been excluded from the study.

However, in our architecture we have taken 4096 samples, the reason has been discussed in section 2.4 . These samples are upscaled by 2^9 then used for all further processing throughout the work and again down scaled by 2^9 for both decomposition and reconstruction to get the desired output. This scaling factor has been decided based on the SNR evaluation. To essay the implementation of the algorithm we break the inbuilt matlab code to some easily implementtable code using DWT for both baseline wandering (< 1Hz) and denoising (50-60 Hz) and checked the performance statistics. In this proposed architecture, we are not dealing with the denoising (50-60 Hz) part, because of its less significant values to that of baseline wandering

(< 1Hz) values, while doing the wavelet transformation analysis. Hence effect of denoising (50-60 Hz) values are very minimal, so we can ignore it. Though from algorithmic prospective Symmlet is the best proved wavelet[14],however from architectural point view Harr is the best known[19]. Hence to conclude, which wavelet to be taken as mother wavelet we evaluated the R^2 statistics for baseline wandering and denoising using both Harr and Symmlet for all possible combination as shown in Fig. 2.(a) In order to make the architectue low complex we took the least complex Harr wavelet as mother wavelet, however the performance statistics shown in Fig. 2 (a) was worst with Harr and the best with Symmlet ,hence we stick to Symmlet as the mother wavelet.

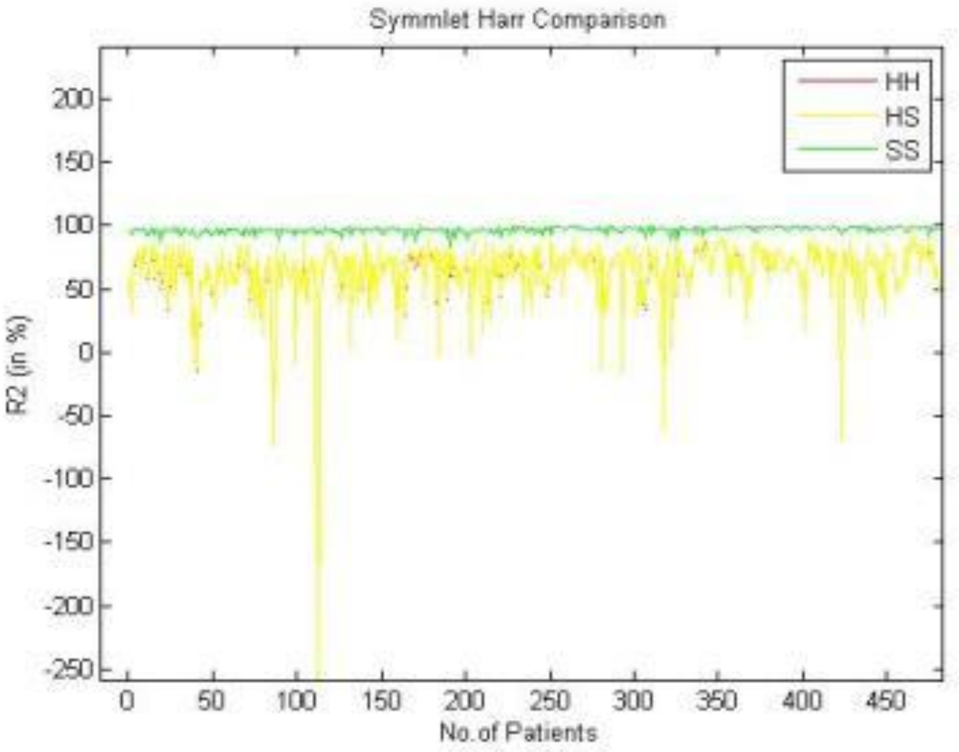


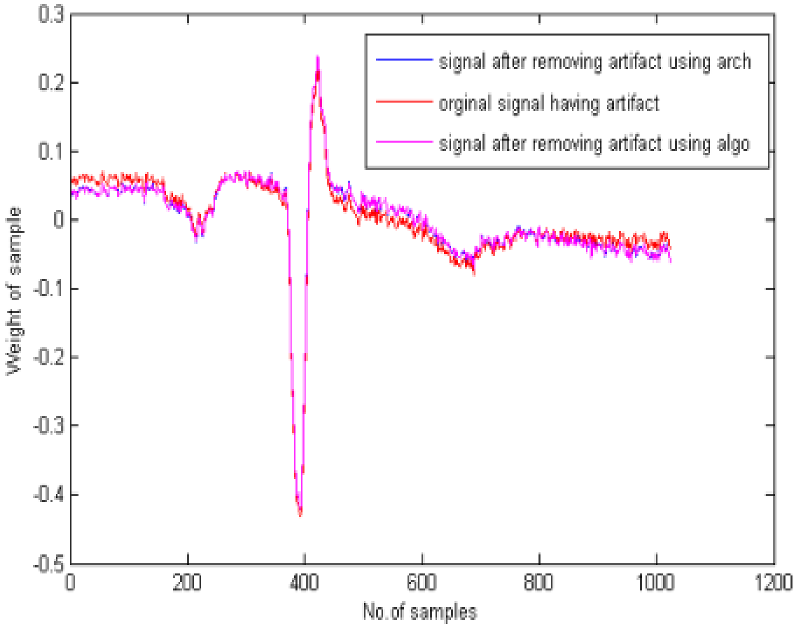
Fig. 2. Harr Vs. Symmlet comparison

2.4. Optimized Number of inputs

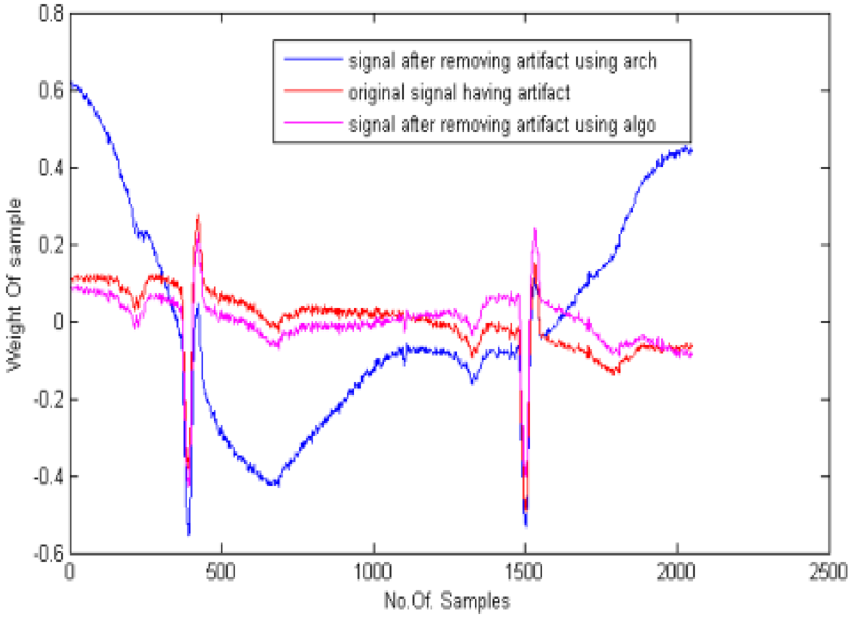
Though processing more no.of samples will give more time resolution as well as frequency resolution, however in architectural prospective this will intern increase the hardware complexity and memory requirement leading to more processing time and more power consumption. Hence to obtain a trade-off between the accuracy and hardware complexity along with memory requirement we have performed comparison shown in Fig. 3 .With 1024 samples Fig. 3 clearly shows that there is not much variation in signal having artifact and signal after removing artifact using algorithm and architecture, hence artifact has not been removed efficiently, however if no.of samples are 2048, there is significant degradation in the reconstructed signal by using algo. (magenta) and arch .(blue). Though with 4096 and 8192 samples which are giving an accurate result for architecture to that of already proposed algorithm, we conclud –

ed to have, input samples of 2^12 as a tradeoff between the hardware complexity and accuracy.

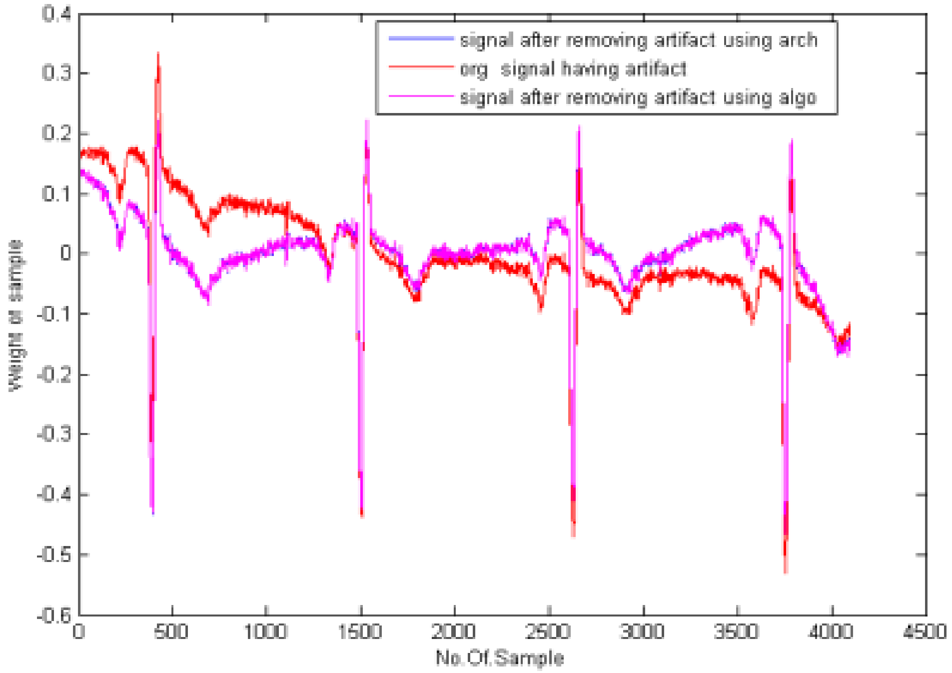
1024-Samples comparison-



2048-Samples comparison-



4096-Samples comparison-



8192-Samples comparison-

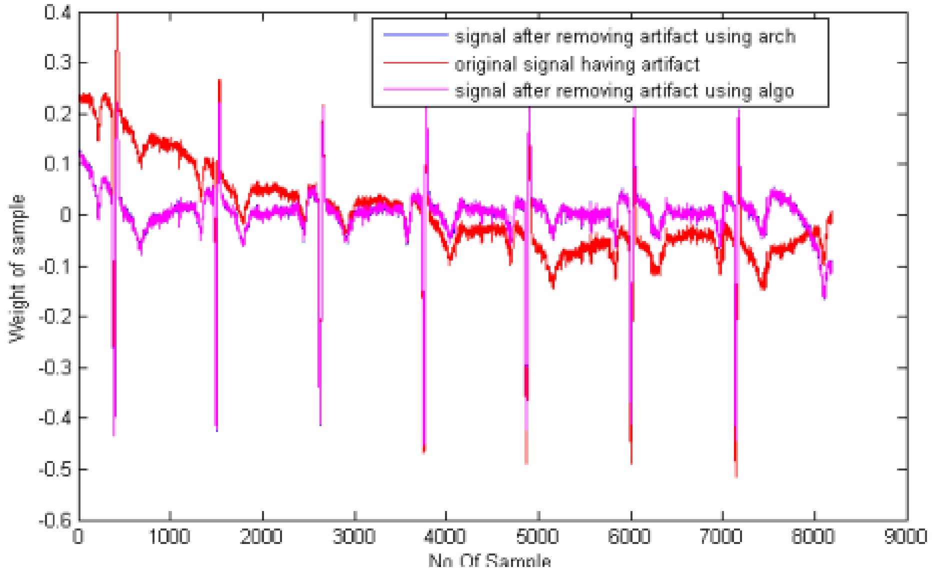


Fig. 3. Comparision among the signal having artifact(red),signal af-ter removing artifact using algorithm(magenta),signal after removing artifact using architecture(blue),(a)1024-samples,(b)2048-samples,(c)4096-samples,(d)8192-samples

2.5. Low complexity

The proposed architecture not only optimizes the algorithm with no. of. inputs but also here we have proposed a multiplier less architecture for the computational intensive wavelet analysis module. This is neither the mere replacement of multiplier with the adder nor the implementation of distributed arithmetic where

$$y = x_1 h_1 + x_2 h_2 + x_3 h_3 + \ldots\ldots + x_n h_n$$

where h1,h2,h3,....hn are the filter coefficient.

The implementation of distributed arithmatic imposes memory as the penalty . However in this architecture , just by exploiting the value of the coefficient, we can able to implement a multiplier less architecture, which will again led to the most desirable low complex architecture for rural health care environment. with the precludance of subsampling and upsampling stage again we have reduced the no of transistor reqirements too.Fig. 4 shows a high no. of transistor save by replacing the conventional design where multipliers are being used with our architecture .

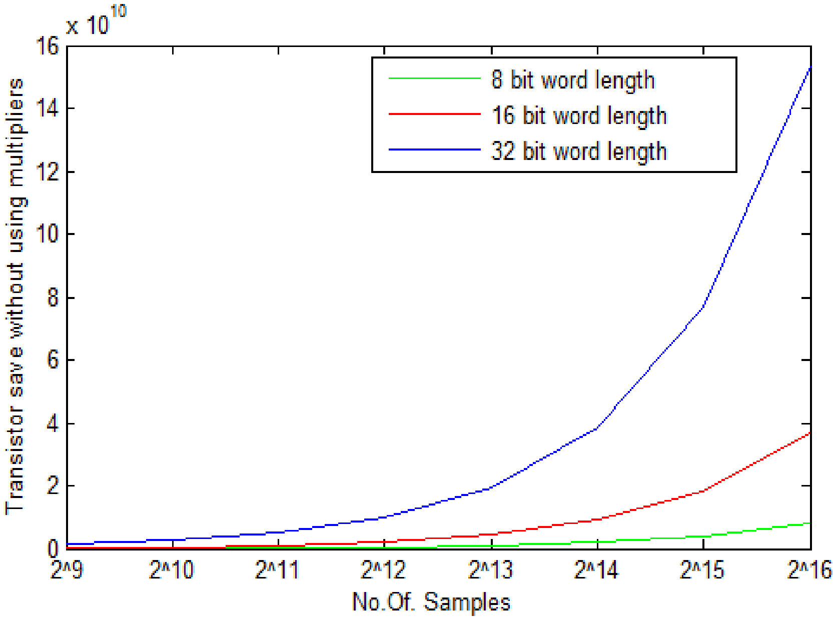


Fig.4.Transistor save with increase in word length

2.6. Robust

Along with the low complexity and low power ,the robust-ness of the architecture is a major concern while implementing an architecture. Pertaining to that we analyzed the algorithm from architectural point of view and came up with a robust architecture . We analyzed and tested our architecture for a range of 101 patients with our already proposed algorithm, whose details are tabulated in Table I , Table II, Table III in terms of R2, correlation (rx), regression (bx) being described respectively in Section-IV .

2.7 Architecture Details

Here, we propose an low complexity, robust architecture of the preprocessing module (which is the most computational intensive part) for the CVD detection system. The generic description of proposed architecture is as follows

$$h_i = \sum_k \sigma_k 2^k$$

Where σ_k= -1 or +1

Where hi is the filter coefficient upscaled fixed

$$x_i h_i = x_i[\sum_k \sigma_k 2^k] = \sum_k \sigma_k (x_i 2^k)$$

Where xi is the input samples which will get operated on hi. The entire architecture is being divided into 3 sub-blocks (controlled by a controller logic) consisting of decomposition, recon – struction and then after subtraction. This whole decomposition, reconstruction can be achieved by left shift or right shift and sum operation. Thereby it removes the computational intensive multipliers by large amount. The subtraction block will subtract the reconstructed signal from the original signal, which mean to subtraction of artifact from the original signal, finally giving out a artifact free 3-lead signal. In our architecture i ranges from 1 to 16 , because the wavelet considered in our architecture is Symmlet-8,which is having 16 samples. The generic view of the above mentioned operation is as follows. Lets say ,the total no. of input samples is ’n’.These total input samples has been divided into subsamples ,having 16 samples each, to do the above operation. Hence after doing the decomposition we will have ’n=(2^9)’ samples at the 9th level. These samples corresponds to the samples affected by artifact, which is again being reconstructted up to 9th level, so that we can do the subtraction. For our architecture n is taken as 4096 , considering the algorithmic and architectural holistic view. While doing the wavelet analysis in conventional approach we have to do an intermediate down sampling after every decomposition and up sampling after every reconstruction stage. However, in our architecture we have achieved the output without doing the down sampling and up sampling stage, thereby we reducing the delay factor. is shown in Fig. 5

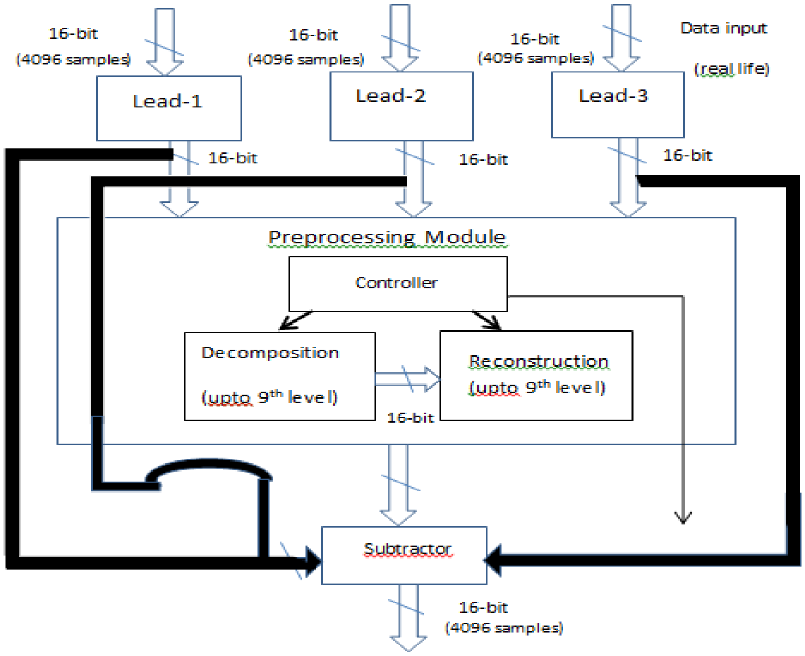


Fig . 5 . An overview of the proposed architecture

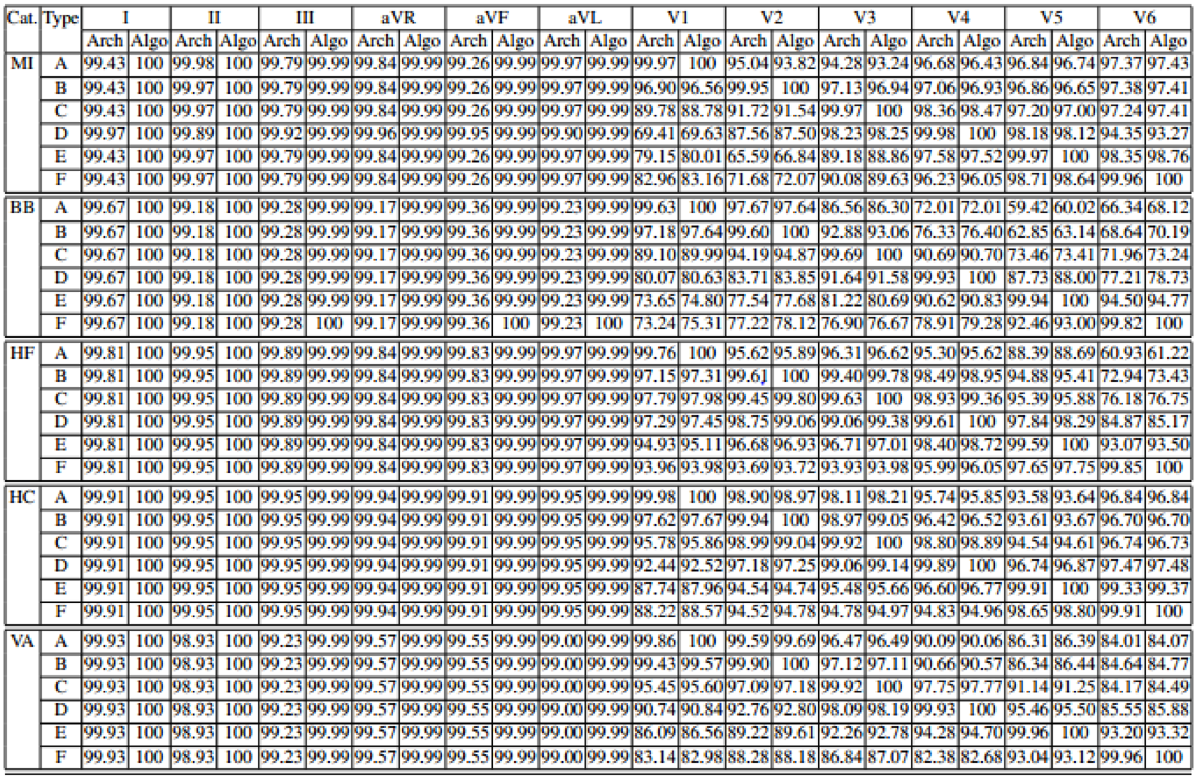
3. RESULTS AND DISCUSSION

3.1. R^2, Correlation and Regression statistics comparision between algo and arch-

In this architecture, the reconstruction of 12-leads has been done by using R3L systems i.e. lead-I, lead-II and any one of precordial leads as the basis leads and is being tested. Table I presents the R2, correlation rx and regression bx coefficient values of R3L systems to S12 system for the reconstruction of SotA 12-lead using algorithm(denoted as algo.) and architecture (denoted as arch.).

TABLE I

R^2 STATISTICS COMPARISION BETWEEN ARCH AND ALGO.FOR THE RECONSTRUCTION OF REDUCED 3 LEAD TO STANDARD 12 LEAD

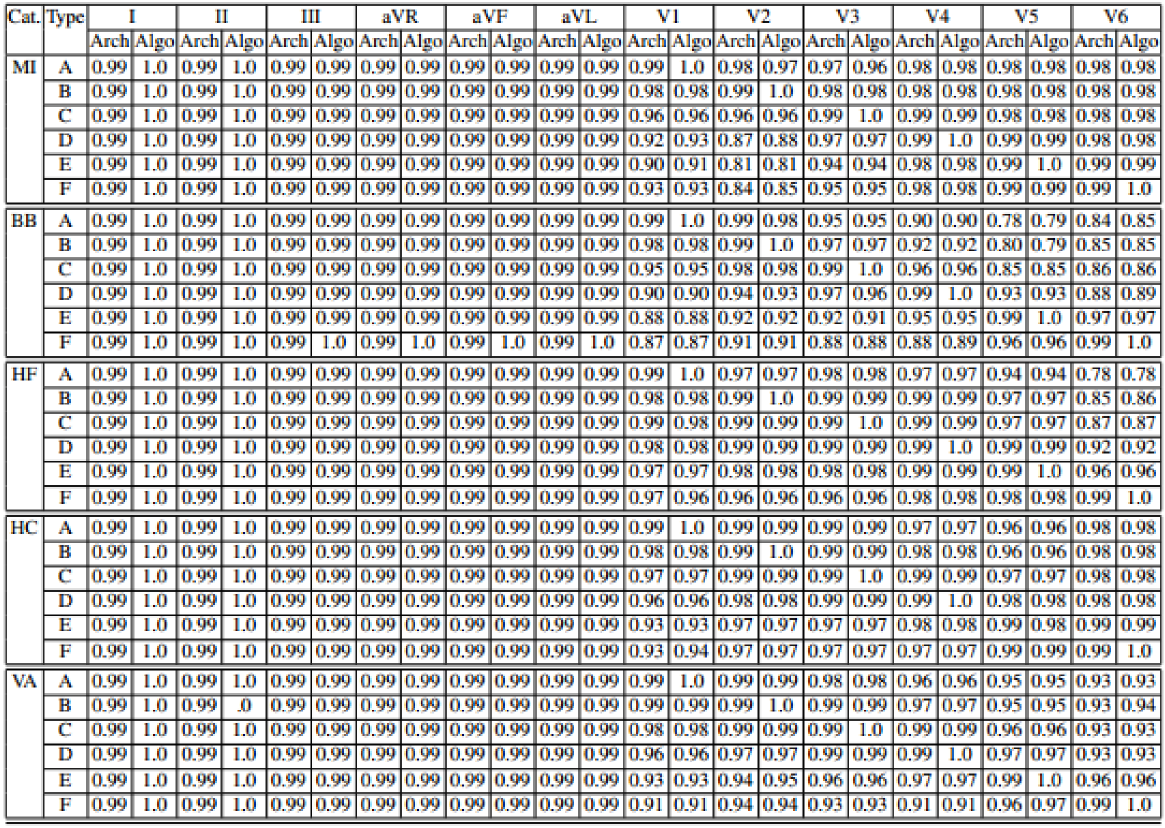


Cat.	Type	I		II		III		aVR		aVF		aVL		V1		V2		V3		V4		V5		V6	
		Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo
MI	A	99.43	100	99.98	100	99.79	99.99	99.84	99.99	99.26	99.99	99.97	99.99	99.97	100	95.04	93.82	94.28	93.24	96.68	96.43	96.84	96.74	97.37	97.43
	B	99.43	100	99.97	100	99.79	99.99	99.84	99.99	99.26	99.99	99.97	99.99	96.90	96.56	99.95	100	97.13	96.94	97.06	96.93	96.86	96.65	97.38	97.41
	C	99.43	100	99.97	100	99.79	99.99	99.84	99.99	99.26	99.99	99.97	99.99	89.78	88.78	91.72	91.54	99.97	100	98.36	98.47	97.20	97.00	97.24	97.41
	D	99.97	100	99.89	100	99.92	99.99	99.96	99.99	99.95	99.99	99.90	99.99	69.41	69.63	87.56	87.50	98.23	98.25	99.98	100	98.18	98.12	94.35	93.27
	E	99.43	100	99.97	100	99.79	99.99	99.84	99.99	99.26	99.99	99.97	99.99	79.15	80.01	65.59	66.84	89.18	88.86	97.58	97.52	99.97	100	98.35	98.76
	F	99.43	100	99.97	100	99.79	99.99	99.84	99.99	99.26	99.99	99.97	99.99	82.96	83.16	71.68	72.07	90.08	89.63	96.23	96.05	98.71	98.64	99.96	100
BB	A	99.67	100	99.18	100	99.28	99.99	99.17	99.99	99.36	99.99	99.23	99.99	99.63	100	97.67	97.64	86.56	86.30	72.01	72.01	59.42	60.02	66.34	68.12
	B	99.67	100	99.18	100	99.28	99.99	99.17	99.99	99.36	99.99	99.23	99.99	97.18	97.64	99.60	100	92.88	93.06	76.33	76.40	62.85	63.14	68.64	70.19
	C	99.67	100	99.18	100	99.28	99.99	99.17	99.99	99.36	99.99	99.23	99.99	89.10	89.99	94.19	94.87	99.69	100	90.69	90.70	73.46	73.41	71.96	73.24
	D	99.67	100	99.18	100	99.28	99.99	99.17	99.99	99.36	99.99	99.23	99.99	80.07	80.63	83.71	83.85	91.64	91.58	99.93	100	87.73	88.00	77.21	78.73
	E	99.67	100	99.18	100	99.28	99.99	99.17	99.99	99.36	99.99	99.23	99.99	73.65	74.80	77.54	77.68	81.22	80.69	90.62	90.83	99.94	100	94.50	94.77
	F	99.67	100	99.18	100	99.28	100	99.17	99.99	99.36	100	99.23	100	73.24	75.31	77.22	78.12	76.90	76.67	78.91	79.28	92.46	93.00	99.82	100
HF	A	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	99.76	100	95.62	95.89	96.31	96.62	95.30	95.62	88.39	88.69	60.93	61.22
	B	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	97.15	97.31	99.6]	100	99.40	99.78	98.49	98.95	94.88	95.41	72.94	73.43
	C	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	97.79	97.98	99.45	99.80	99.63	100	98.93	99.36	95.39	95.88	76.18	76.75
	D	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	97.29	97.45	98.75	99.06	99.06	99.38	99.61	100	97.84	98.29	84.87	85.17
	E	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	94.93	95.11	96.68	96.93	96.71	97.01	98.40	98.72	99.59	100	93.07	93.50
	F	99.81	100	99.95	100	99.89	99.99	99.84	99.99	99.83	99.99	99.97	99.99	93.96	93.98	93.69	93.72	93.93	93.98	95.99	96.05	97.65	97.75	99.85	100
HC	A	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	99.98	100	98.90	98.97	98.11	98.21	95.74	95.85	93.58	93.64	96.84	96.84
	B	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	97.62	97.67	99.94	100	98.97	99.05	96.42	96.52	93.61	93.67	96.70	96.70
	C	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	95.78	95.86	98.99	99.04	99.92	100	98.80	98.89	94.54	94.61	96.74	96.73
	D	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	92.44	92.52	97.18	97.25	99.06	99.14	99.89	100	96.74	96.87	97.47	97.48
	E	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	87.74	87.96	94.54	94.74	95.48	95.66	96.60	96.77	99.91	100	99.33	99.37
	F	99.91	100	99.95	100	99.95	99.99	99.94	99.99	99.91	99.99	99.95	99.99	88.22	88.57	94.52	94.78	94.78	94.97	94.83	94.96	98.65	98.80	99.91	100
VA	A	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	99.86	100	99.59	99.69	96.47	96.49	90.09	90.06	86.31	86.39	84.01	84.07
	B	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	99.43	99.57	99.90	100	97.12	97.11	90.66	90.57	86.34	86.44	84.64	84.77
	C	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	95.45	95.60	97.09	97.18	99.92	100	97.75	97.77	91.14	91.25	84.17	84.49
	D	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	90.74	90.84	92.76	92.80	98.09	98.19	99.93	100	95.46	95.50	85.55	85.88
	E	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	86.09	86.56	89.22	89.61	92.26	92.78	94.28	94.70	99.96	100	93.20	93.32
	F	99.93	100	98.93	100	99.23	99.99	99.57	99.99	99.55	99.99	99.00	99.99	83.14	82.98	88.28	88.18	86.84	87.07	82.38	82.68	93.04	93.12	99.96	100

The basis lead set consisting of leads I, II, V1 has been denoted by A , basis lead set consisting of leads I, II, V2 is denoted by B and so on. We will mainly concern ourselves to R2 values for comparison purpose. Since leads I and II are involved in all the basis lead set, the resulting R2, rx and bx values of those corresponding leads are 100%, 1.0 and 1.0 respectively for the already proposed algo. , however for our proposed architecture, because of word length limitation in hardware implementation the cor-responding values are > 99%,> 0:9 and > 0:9

TABLE II

r_x STATISTICS COMPARISION BETWEEN ARCH AND ALGO.FOR THE RECONSTRUCTION OF REDUCED 3 LEAD TO STANDARD 12 LEAD

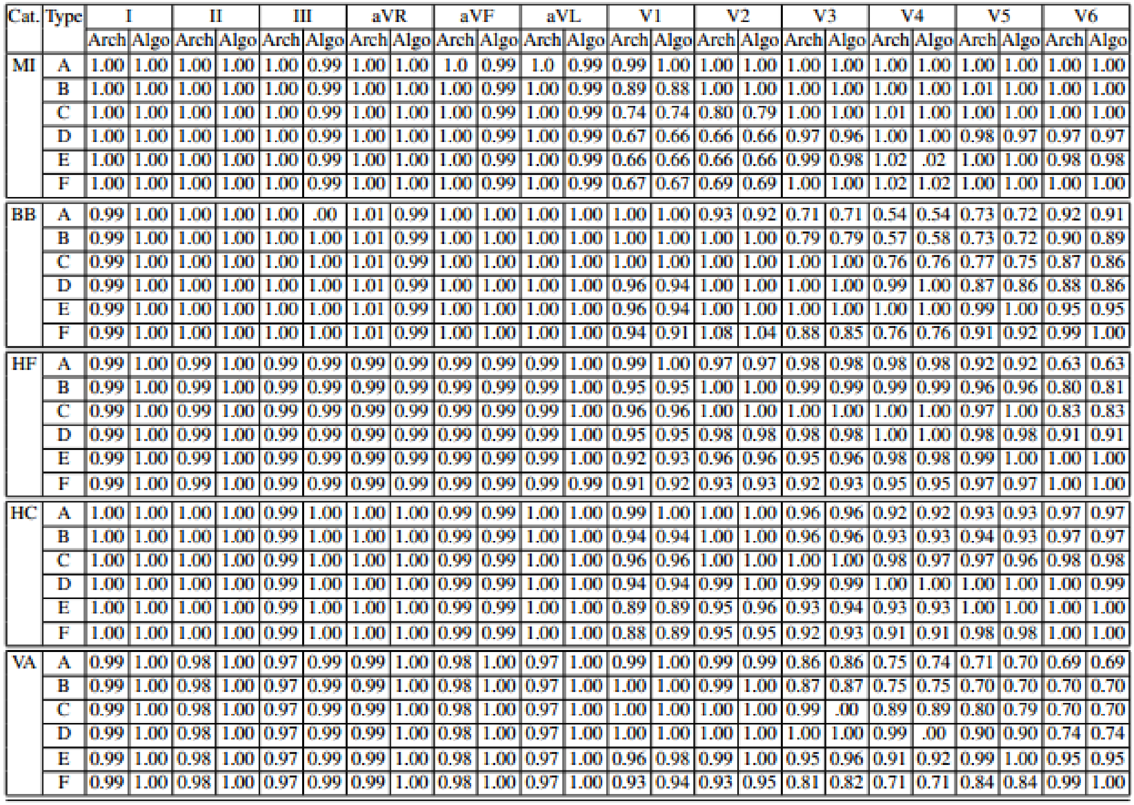


Cat.	Type	I		II		III		aVR		aVF		aVL		V1		V2		V3		V4		V5		V6	
		Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo
MI	A	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.98	0.97	0.97	0.96	0.98	0.98	0.98	0.98	0.98	0.98
	B	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	1.0	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
	C	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.96	0.96	0.96	0.96	0.99	1.0	0.99	0.99	0.98	0.98	0.98	0.98
	D	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.92	0.93	0.87	0.88	0.97	0.97	0.99	1.0	0.99	0.99	0.98	0.98
	E	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.90	0.91	0.81	0.81	0.94	0.94	0.98	0.98	0.99	1.0	0.99	0.99
	F	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.93	0.93	0.84	0.85	0.95	0.95	0.98	0.98	0.99	0.99	0.99	1.0
BB	A	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.99	0.98	0.95	0.95	0.90	0.90	0.78	0.79	0.84	0.85
	B	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	1.0	0.97	0.97	0.92	0.92	0.80	0.79	0.85	0.85
	C	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.95	0.95	0.98	0.98	0.99	1.0	0.96	0.96	0.85	0.85	0.86	0.86
	D	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.90	0.90	0.94	0.93	0.97	0.96	0.99	1.0	0.93	0.93	0.88	0.89
	E	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.88	0.88	0.92	0.92	0.92	0.91	0.95	0.95	0.99	1.0	0.97	0.97
	F	0.99	1.0	0.99	1.0	0.99	1.0	0.99	1.0	0.99	1.0	0.99	1.0	0.87	0.87	0.91	0.91	0.88	0.88	0.88	0.89	0.96	0.96	0.99	1.0
HF	A	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.97	0.97	0.98	0.98	0.97	0.97	0.94	0.94	0.78	0.78
	B	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	1.0	0.99	0.99	0.99	0.99	0.97	0.97	0.85	0.86
	C	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	1.0	0.99	0.99	0.97	0.97	0.87	0.87
	D	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	0.99	0.99	0.99	0.99	1.0	0.99	0.99	0.92	0.92
	E	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99	0.99	1.0	0.96	0.96
	F	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.96	0.96	0.96	0.96	0.96	0.98	0.98	0.98	0.98	0.99	1.0
HC	A	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.96	0.98	0.98
	B	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	1.0	0.99	0.99	0.98	0.98	0.96	0.96	0.98	0.98
	C	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.99	0.99	0.99	1.0	0.99	0.99	0.97	0.97	0.98	0.98
	D	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.96	0.96	0.98	0.98	0.99	0.99	0.99	1.0	0.98	0.98	0.98	0.98
	E	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.93	0.93	0.97	0.97	0.97	0.97	0.98	0.98	0.99	0.98	0.99	0.99
	F	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.93	0.94	0.97	0.97	0.97	0.97	0.97	0.97	0.99	0.99	0.99	1.0
VA	A	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.99	0.99	0.98	0.98	0.96	0.96	0.95	0.95	0.93	0.93
	B	0.99	1.0	0.99	.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.0	0.99	0.99	0.97	0.97	0.95	0.95	0.93	0.94
	C	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	0.99	0.99	1.0	0.99	0.99	0.96	0.96	0.93	0.93
	D	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.96	0.96	0.97	0.97	0.99	0.99	0.99	1.0	0.97	0.97	0.93	0.93
	E	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.93	0.93	0.94	0.95	0.96	0.96	0.97	0.97	0.99	1.0	0.96	0.96
	F	0.99	1.0	0.99	1.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.91	0.91	0.94	0.94	0.93	0.93	0.91	0.91	0.96	0.97	0.99	1.0

respectively. It can be seen that due to proximity effect, the leads (mostly the precordial leads) close to basis lead reconstructed with high R2 , rx and bx values as compared to others e.g for lead set-D (basis lead as lead-I,lead-II,lead-V4)of a Heart Faliure(HF) patient is 97.29%, 98.75%,99.06%,99.61%,97.84%,84.87% for reconstruction of precordial leads V1, V2, V3, V4, V5,V6 respectively. We can clearly distinguish that the reconstruction value for lead-V4 is the highest followed by other closely placed leads. Augmented leads i. e aVR , aVL, aVF are dependent on lead-I, lead-II, hence their R2 of reconstruction is > 99% for all above mentioned basis set. Fig.4 shows a comparison of hardware complexity analysis with and without using the multiplier, which intern drastically reduces the complexity of the architecture. The red color plot shows the no. of transistor save for a word length of 16 bit with increase in no. of samples from 2^9 to 2 ^16. Transistor save by using our architecture instead of conventional for 2^n samples, where n = 9 to16 are 286743168.0, 573486336.0, 1146972672.0, 2293945344.0, 4587890688.0, 9175781376.0, 18351562752 .0 , 36703125504.0 respectively. As this architecture the optimized no. of input samples are 2^12 with a word length of 16-bit ,hence the transistor save is 2293945344.0.Similarly we have analyzed our transistor save for 16, 32 and 64 bit word length The transistor count has been increased with the increase in word length and also with the increase in no. of samples.

TABLE III

b_x statistics comparision between Arch and Algo.for the reconstruction of Reduced 3 lead to Standard 12 lead



Cat.	Type	I		II		III		aVR		aVF		aVL		V1		V2		V3		V4		V5		V6	
		Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo	Arch	Algo
MI	A	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.0	0.99	1.0	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	B	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.89	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00
	C	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.74	0.74	0.80	0.79	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00
	D	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.67	0.66	0.66	0.66	0.97	0.96	1.00	1.00	0.98	0.97	0.97	0.97
	E	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.66	0.66	0.66	0.66	0.99	0.98	1.02	.02	1.00	1.00	0.98	0.98
	F	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.67	0.67	0.69	0.69	1.00	1.00	1.02	1.02	1.00	1.00	1.00	1.00
BB	A	0.99	1.00	1.00	1.00	1.00	.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.92	0.71	0.71	0.54	0.54	0.73	0.72	0.92	0.91
	B	0.99	1.00	1.00	1.00	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	0.79	0.57	0.58	0.73	0.72	0.90	0.89
	C	0.99	1.00	1.00	1.00	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.76	0.76	0.77	0.75	0.87	0.86
	D	0.99	1.00	1.00	1.00	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	0.96	0.94	1.00	1.00	1.00	1.00	0.99	1.00	0.87	0.86	0.88	0.86
	E	0.99	1.00	1.00	1.00	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	0.96	0.94	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.95	0.95
	F	0.99	1.00	1.00	1.00	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	0.94	0.91	1.08	1.04	0.88	0.85	0.76	0.76	0.91	0.92	0.99	1.00
HF	A	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	1.00	0.97	0.97	0.98	0.98	0.98	0.98	0.92	0.92	0.63	0.63
	B	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.95	0.95	1.00	1.00	0.99	0.99	0.99	0.99	0.96	0.96	0.80	0.81
	C	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.96	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	0.83	0.83
	D	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.95	0.95	0.98	0.98	0.98	0.98	1.00	1.00	0.98	0.98	0.91	0.91
	E	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.92	0.93	0.96	0.96	0.95	0.96	0.98	0.98	0.99	1.00	1.00	1.00
	F	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.91	0.92	0.93	0.93	0.92	0.93	0.95	0.95	0.97	0.97	1.00	1.00
HC	A	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	1.00	1.00	1.00	0.96	0.96	0.92	0.92	0.93	0.93	0.97	0.97
	B	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.94	0.94	1.00	1.00	0.96	0.96	0.93	0.93	0.94	0.93	0.97	0.97
	C	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.96	0.96	1.00	1.00	1.00	1.00	0.98	0.97	0.97	0.96	0.98	0.98
	D	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.94	0.94	0.99	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.99
	E	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.89	0.89	0.95	0.96	0.93	0.94	0.93	0.93	1.00	1.00	1.00	1.00
	F	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.88	0.89	0.95	0.95	0.92	0.93	0.91	0.91	0.98	0.98	1.00	1.00
VA	A	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	0.99	1.00	0.99	0.99	0.86	0.86	0.75	0.74	0.71	0.70	0.69	0.69
	B	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	1.00	1.00	0.99	1.00	0.87	0.87	0.75	0.75	0.70	0.70	0.70	0.70
	C	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.99	.00	0.89	0.89	0.80	0.79	0.70	0.70
	D	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	.00	0.90	0.90	0.74	0.74
	E	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	0.96	0.98	0.99	1.00	0.95	0.96	0.91	0.92	0.99	1.00	0.95	0.95
	F	0.99	1.00	0.98	1.00	0.97	0.99	0.99	1.00	0.98	1.00	0.97	1.00	0.93	0.94	0.93	0.95	0.81	0.82	0.71	0.71	0.84	0.84	0.99	1.00

Table I, Table II, Table III are the 3 comparison tables in terms of R^2, correlation rx and regression bx for different category of patient taken from PTBDB database. If, we compare the

R^2 statistics between the algorithm and architecture instead of 100% we are getting more than 99% .Comparison of correlation r x and regression bx between the comparison of algorithm and architecture it is more than 0.9. This happens, because of hardware limitation, as we can not take a higher word length because of increase in hardware complexity. Fig.6 shows the reconstruction of 12-lead ECG signal from the reduced 3-lead system using different sets of lead. The figures describe the same as we got the statistics from table.

Reconstructed 12-Lead Signal Using Reduced 3-Lead System-

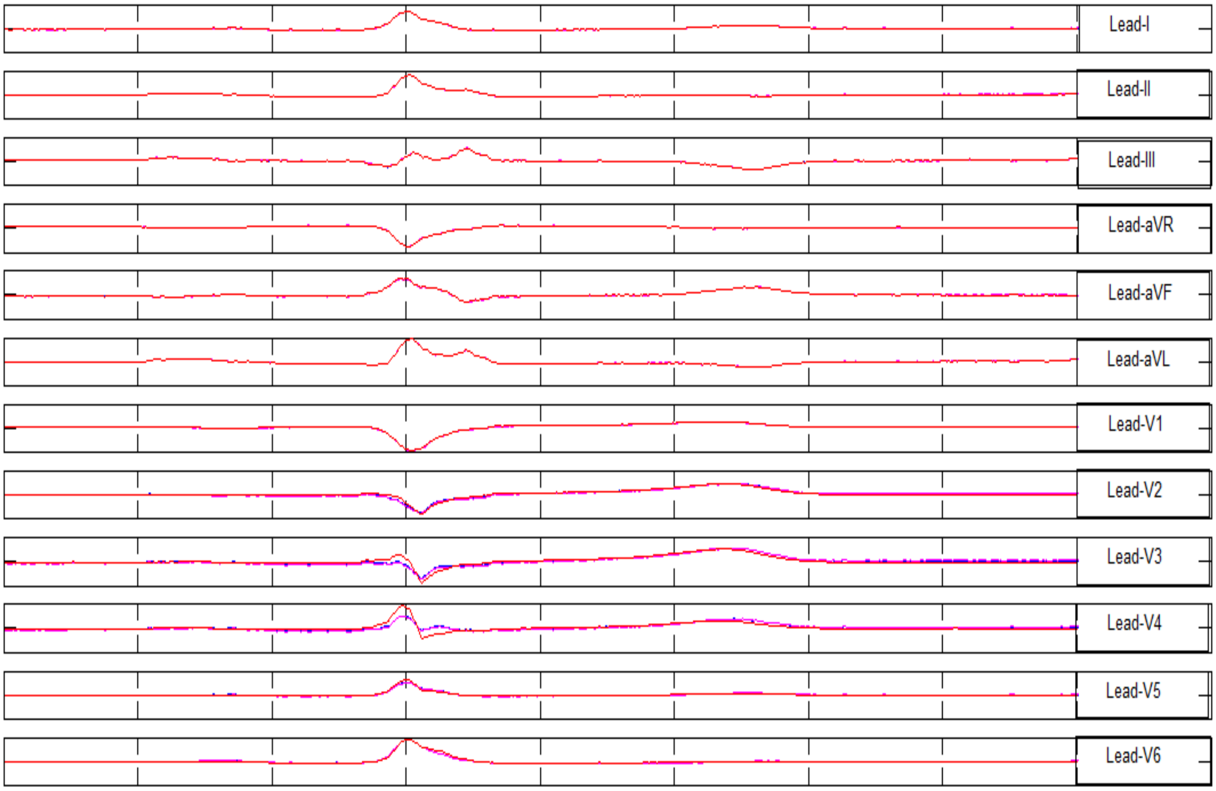


Fig-6 Reconstruction of 12-lead signal using the reduced 3-Lead architecture and algorithm .
Red color is for original 12-lead ECG signal ,
Blue color is for recon .of 12-lead using already proposed reduced 3-Lead algo. ,
Magenta is for recon. of 12-lead using our proposed hardware architecture for reduced 3-lead.

3.2 **FPGA** prototype of proposed architecture-

The proposed architecture has been prototyped on FPGA board with version Virtex-7 with a clock frequency of 229.929 MHz , which clearly specifies the speed of the proposed work .The result has been analyzed and verified using Chipscope Pro analyzer. The snap shot of the FPGA prototype is being shown in Fig-7 and Fig-8 shows the denoised data that coming as the output of the architecture using Chipscope-pro analyzer.

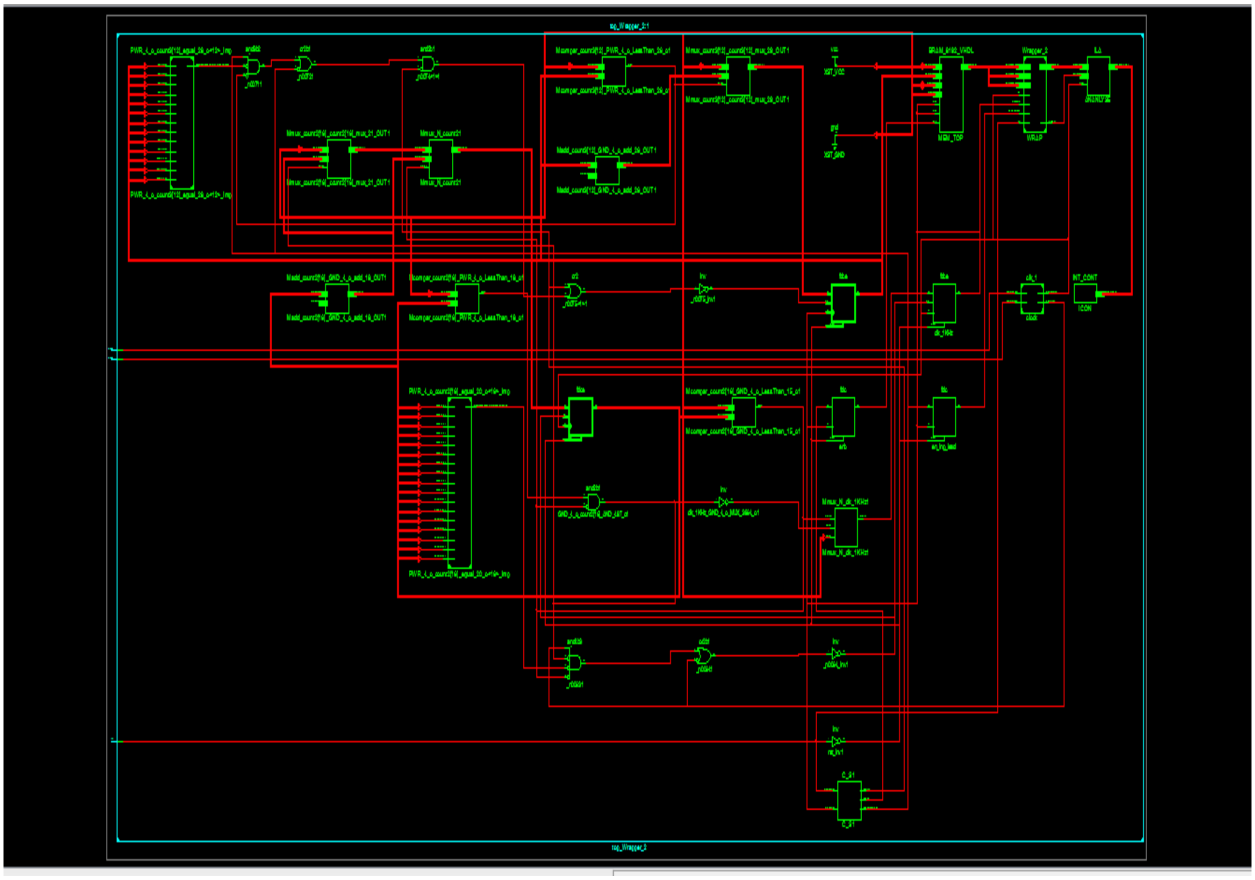
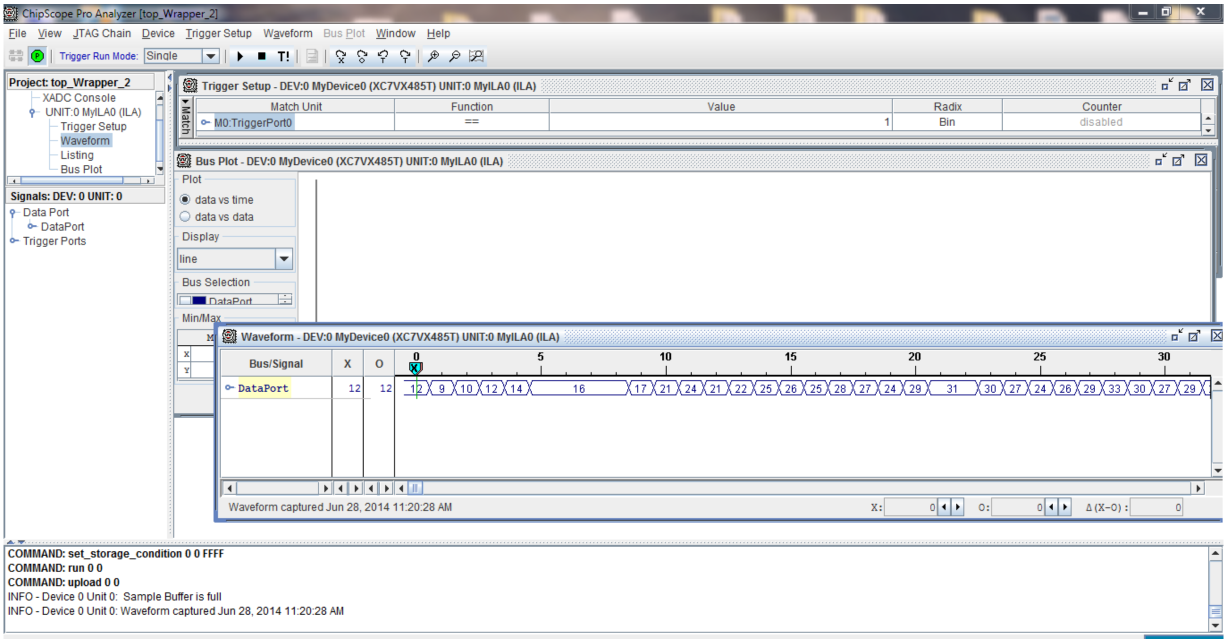


Fig -7. Block Diagram Implementations of proposed architecture On FPGA



Match Unit	Function	Value	Radix	Counter
M0:TriggerPort0	==	1	Bin	disabled

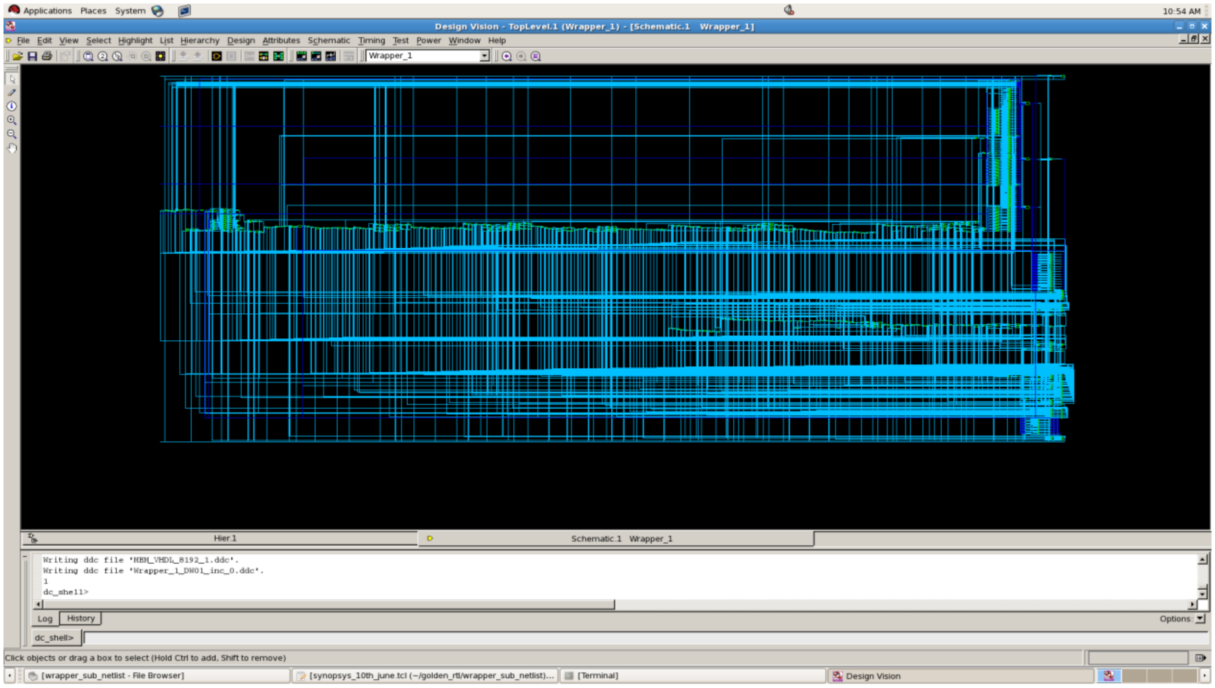
```
Waveform captured Jun 28, 2014 11:20:28 AM
```

```
COMMAND: set_storage_condition 0 0 FFFF
COMMAND: run 0 0
COMMAND: upload 0 0
INFO - Device 0 Unit 0:  Sample Buffer is full
INFO - Device 0 Unit 0: Waveform captured Jun 28, 2014 11:20:28 AM
```

Fig -8 . Output result verification using chip scope pro analyzer

3.3 ASIC implimentation of proposed architecture-

.



```
Writing ddc file 'MEM_VHDL_8192_1.ddc'.
Writing ddc file 'Wrapper_1_DW01_inc_0.ddc'.
1
dc_shell>
```

Click objects or drag a box to select (Hold Ctrl to add, Shift to remove)

Fig -9 ASIC implementation of the preprocessing module.

The ASIC implimentation of the proposed architecture has been done using 130nm technology UMC library and the output has been verified in each and every step of the ASIC flow .The area result from ASIC implimentation is 20.54 mm square and a power consumption of 66.29 mW without doing any optimization.

4. Conclusion and Future work

The concept of personalized lead reconstruction has drawn a milestone towards the advancement of the pervasive health management system both in rural and urban area. This will intern provide a reliable solution for the patient suffering from CVD by taking care all the exigencies occurred by it. As, mentioned earlier, in our previous work we have proposed an algorithm, a step towards the personalized health care is coded in mat lab .In order to realize, the proposed mat lab code, in this paper we are proposing a low complex, robust architecture to spoor the step towards the hardware implementation for the most computational intensive part of the algorithm.

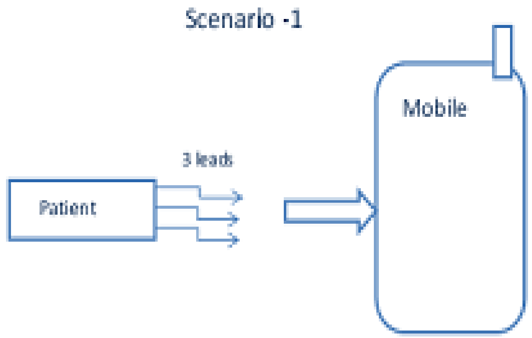


Fig -10(a) Patient is physically available at the health care center.

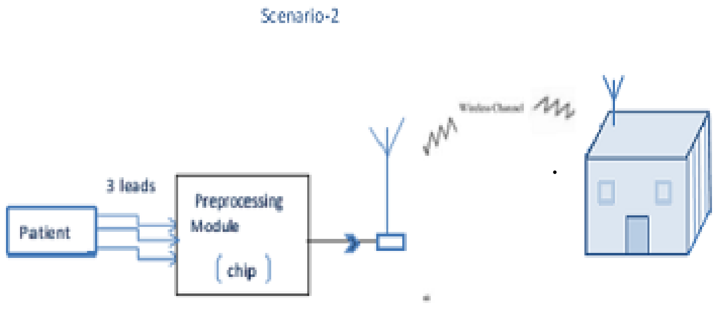


Fig-10 (b)Patient is present at any remote place

The Table I , Table II and Table III clearly provide a comparison statistics between the already proposed algorithm and the proposed architecture . The R^2 of reconstruction for algorithm are100%,100%,99.99%,99.99%,99.99%,99.99%,97.45%,99.06%,99.38%,100%,98.29%,85.17% whereas the corresponding R^2 for architecture .are 99.81%, 99.95%, 99.89%, 99.84%, 99.83%, 99.97%, 97.29%, 98.75%, 99.06%, 99.61%, 97.84%, 84.87% using the lead set-D for a patient suffering from heart failure. This gives a clear remark of the accuracy of the proposed architecture. The Fig.10 also gives an aid as the future work of our proposed architecture. On the other hand, the hardware complexity of the architecture has been reduced drastically by a transistor count of 2293945344.0 with a input of 2^12 samples and a word length of 16-bit which intern reduces the power consumption of the total architecture .This will be a great advantage towards the rural health care system. The future work includes, a complete personalized health care system, that can be visualized as shown in Fig. 1 both in scenario-1 and scenario-2.The scenario-1 , describes the case where the doctors need not carry the bulky SotA ECG machine but can carry a 3-lead ECG machine like a stethoscope and take the signal in patients physical presence and do all the necessary signal preprocessing using our architecture (as a tiny hardware module) for removing the artifact from the signals and reconstruct the 12-lead ECG signals by using the mobile platform which will be online for both the Scenario. The scenario-2 , describes the offline mode of personalized health care system, where patients can stay at their turf ,do the necessary signal preprocessing and send the signal wirelessly to the health care centre ,where the 12-lead SotA signal will be reconstructed,for further diagnosis.

5. Paper Publication-

Utkalika Panda, Sidharth Maheshwari, Gayathri Padma, Murugaiyan Thendral, Amit Acharyya, Paolo Emilio Puddu and Michele Schiariti, "**Personalised system-on-chip for standard 12-lead reconstruction from the reduced from the reduced 3-lead system targeting remote health care",** Computing in Cardiology (CinC)- 2014 (Accepted).

REFERENCES

[1] “Global health risks: mortality and burden of disease attributable to selected major risks,” World Health Organisation, 2009

[2] Liszka, K.J.; Mackin, M.A.; Lichter, M.J.; York, D.W.; Dilip Pil-lai;Rosenbaum, D.S.; ,Keeping a beat on the heart, Pervasive Computing,

[3] IEEE, vol.3, no.4, pp. 42-49, Oct.-Dec. 2004Brechet, L.; Lucas, M.-F.; Doncarli, C.; Farina, D.; ,Compression of Biomedical Signals With Mother Wavelet Optimization and Best-Basis Wavelet Packet Selection, Biomedical Engineering, IEEE Transactions on, vol.54, no.12, pp.2186-2192, Dec. 2007

[4] Alesanco, A.; Garcia, J.; ,Automatic Real-Time ECG Coding Methodol-ogy Guaranteeing Signal Interpretation Quality, Biomedical Engineering,

[5] IEEE Transactions on, vol.55, no.11, pp.2519-2527, Nov. 2008Hoekema, R.; Uijen, G.J.H.; van Oosterum, A.; ,On selecting a Body Surface Mapping Procedure, J Electrocardiol, vol.32, no.2, pp.93-101,April 1999

[6] Dower, G.E.;Yakush, A.; Nazzal, S.B.; Jutzy, R.V.; Ruiz, C.E.; ,De-riving the 12-lead electrocardiogram from four (EASI) electrodes, J Electrocardiol, supplement, pp. 182-187, 1988

[7] Finlay, D.D.; Nugent, C.D.; Kellett, J.G.; Donnelly, M.P.; McCul-lagh,P.J.; Black, N.D.; ,Synthesizing the 12-lead electrocardiogram: Trends and challenges, Eur. J. Intern. Med., vol.18, no.8, pp.566-570,2007

[8] Gregg, R.E.; Zhou, S.H.; Lindauer, J.M.; Feild, D.Q.; Helfenbein,E.D.; ,Where do derived precordial leads fail?, J Electrocardiol, vol.41, pp.546-552, 2008

[9] Nelwan, S.P.; Kors, J.A.; Meij, S.H.; Bemmel, J.H.; Simoons, M.L.;,Reconstruction of the 12-Lead Electrocardiogram from Reduced Lead Sets, J Electrocardiol, vol.37, pp. 11-19, 2004

[10] Nelwan, S.P.; Crater, S.W.; Green, C.L.; Johanson, P.; Dam T.B.;Meij, S.H.; Simoons, M.L.; Krucoff, M.W.; ,Assessment of derived 12-lead electrocardiograms using general and patient-specific reconstruction-strategies at rest and during transient myocardial ischemia, Am J Cardiol, vol.31, pp.1529, 2004

[11] Nelwan, S.P.; Kors, J.A.; Meij, S.H.; ,Minimal Lead Sets for Recon-struction of 12-Lead Electrocardiograms, J Electrocardiol, supplement,vol.33, 2000

[12] Dower, G.E.; ,A lead synthesizer for the Frank system to simulate the standard 12-lead electrocardiogram, J Electrocardiol, vol.1, pp.101, 1968

[13] Dawson, D.; Yang, H.; Malshe, M.; Bukkapatnam, S.T.S.; Benjamin,B.;Komanduri, R.; ,Linear affine transformations between 3-lead (Frank XYZ leads) vectorcardiogram and 12-lead electrocardiogram signals, J Electrocardiol, vol., 42, pp. 622-630, 2009

[14] S. Maheshwari, A. Acharyya, P. Rajalakshmi, P. E. Puddu and M. Schiar-iti (2013), ”Accurate and Reliable 3-Lead to 12-Lead ECG Reconstruc-tion Methodology for Remote

Health Monitoring Applications”; 15th IEEE International Conference on e-Health Networking, Applications and Services (Healthcom, 2013), 9-12 October, 2013, Portugal, 2013.

[15] Frank, E.; ,General theory on heart-vector projection, Circ. Res., vol.2,pp. 258270, 1954

[16] Levkov, C.L.; ,Orthogonal electrocardiogram derived from the limb and chest electrodes of the conventional 12-lead system, Med. Biol. Eng.Comput., vol. 25, pp.155 -164, 1987

[17] Zhang, D.; ,Wavelet Approach for ECG Baseline Wander Correction and Noise Reduction, Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the,vol., no., pp.1212-1215, 2005

[18] Antoniadis, A.; Bigot, J.; Sapatinas, T; ,Wavelet estimators in non-parametric regression: a comparative simulation study, J Stat Software, vol.(issue) 6(6), pp.1-83, 2001

[19] Mazomenos, E., Biswas, D., Acharyya, A., Chen. T., Maharatna, K.,Rosengarten, J., Morgan, J and Curzen, N. (2013), ”A Low-Complexity ECG Feature Extraction Algorithm for Mobile Healthcare Applications”, IEEE Journal of Biomedical and Health Informatics. , Vol. 17, No. 2,March 2013