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Single and multi-step ahead prediction of instant Respiration rate in incremental exercised condition with neural network

Mitul B. Patel [1], Dr. Vipul A. Shah[2]

[1] *Department of Biomedical Engineering, Government Engineering College, Gandhinagar*
[2] *Department of Instrumentation & Control Engineering, Dharmsinh Desai University, Nadiad*

Abstract — *Nowadays cardiopulmonary exercised testing (CPET) becomes popular because of its ability to interpret cardiac and pulmonary fitness in early stage and it is applicable to normal subjects as well as patients. But in incremental kind of exercise, level of physical stress rise with time so there is a chance of overload to the cardiopulmonary system in later phases. So it is always preferable that some tool or facility available in the existing system that can provide information at early. Here we have used NARNET (nonlinear autoregressive neural network) to predict single step and multi-step ahead Instant respiration rate (RR), recorded in incremental exercise conditions. And it is giving a satisfactory result.*

Keywords- *BRUCE protocol, CPET, Incremental exercise, Instant RR, NARNET*

I. INTRODUCTION

CPET is the test for the evolution of cardiopulmonary system under exercised condition. And it is accepted that we can easily interpret the dynamic response of the cardiopulmonary system in physical stress condition. Respiration rate has its own importance in the medical field, it represents the functional status of the respiratory system. Due to physical stress, oxygen requirements of the muscular part rises up by a large amount and to satisfy that need lung has to work above normal capacity. Respiration rate also depends on dimension & compliance of lung, O_2 & CO_2 exchange capability with blood.

Generally, cycle ergometer or Treadmill machine used to provide controlled workload or physical stress. Both types of equipment have their own clinical applications and merits. But in treadmill comparatively large amount of muscular system involvement so overall cardiopulmonary load increase and this is suitable for the sport-related application. Also in treadmill body motion may degrade the quality of signals recorded [1]. In cycle ergometer, there is a motion of an only lower portion of the body so the quality of signal acquired is good enough. Many exercised protocols are available for different medical applications among them Bruce protocol is the globally more involvement in the medical diagnostic field [2]. That's why here in this work we have selected BRUCE protocol for the recording of breathing signal.

II. METHODOLOGY

Proposed work is represented in form of the block diagram in figure 1 and it is discussed below. It is mainly divided into four major blocks.

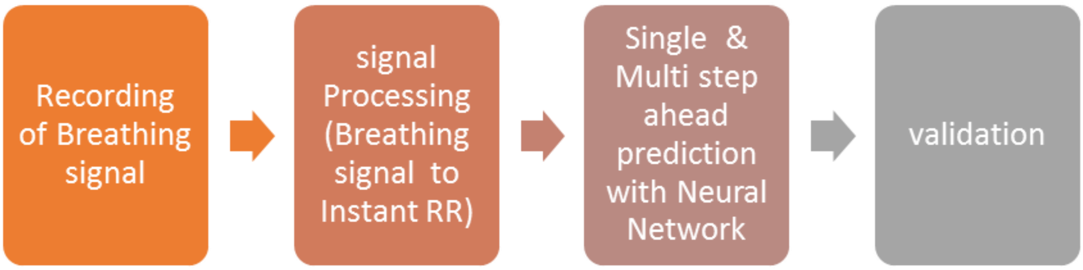

Figure 1. Block diagram of proposed system

2.1. Data acquisitions

We have applied physical stress with the help of Bruce protocol in treadmill machine because our selected subjects are normal and young. Detail stages of BRUCE protocol are given in Table 1. It is not easy for anyone to complete all stages so here all subjects are run for uniformly 9 min (3 stages) only.

During that with the help of thermistor sensor placed in the mask put near the nasal track to record temperature of inhaled and exhaled air. The selected surface temperature sensor is designed for human respiration studies or skin temperature measurements with extremely rapid response time. It is kind of stainless steel temperature sensor. It is 20KΩ NTC thermistor, whose resistance decreases as the temperature increases. The interface measures the resistance value R at a particular temperature and converts back to temperature using below given Steinhart-Hart equation 1.

Stage	Min	% grade	MPH	min/mile	km/h	min/km	METS
1	3	10	1.7	35:18:00	2.7	22:13	4
2	3	12	2.5	24:00:00	4	15:00	7
3	3	14	3.4	17:39	5.5	10:55	10
4	3	16	4.2	14:17	6.8	08:49	13
5	3	18	5	12:00	8	07:30	15
6	3	20	5.5	10:55	8.9	06:44	18
7	3	22	6	10:00	9.7	06:11	21

Table 1. Details of Bruce Protocol [3]

$$T = [k_0 + k_1 (\ln 1000R) + k_1 (\ln 1000R)^3]^{-1} - 273.15 \qquad (01)$$

Where
T is temperature in ^{0}C
R is measured resistance in KΩ,
$K_0 = 1.02119 \text{ X } 10^{-3}$
$K_1 = 2.22468 \text{ X } 10^{-4}$
$K_2 = 1.33342 \text{ X } 10^{-7}$

The collected breathing signal is sampled at 1 KHz sampling frequency and recorded with the help of NI ELVIS II hardware. The pattern of recorded raw breathing signal with the help of thermistor is like a sine wave and shifted upward because the temperature of air never becomes less than surrounding environment temperature, shown in figure 2.

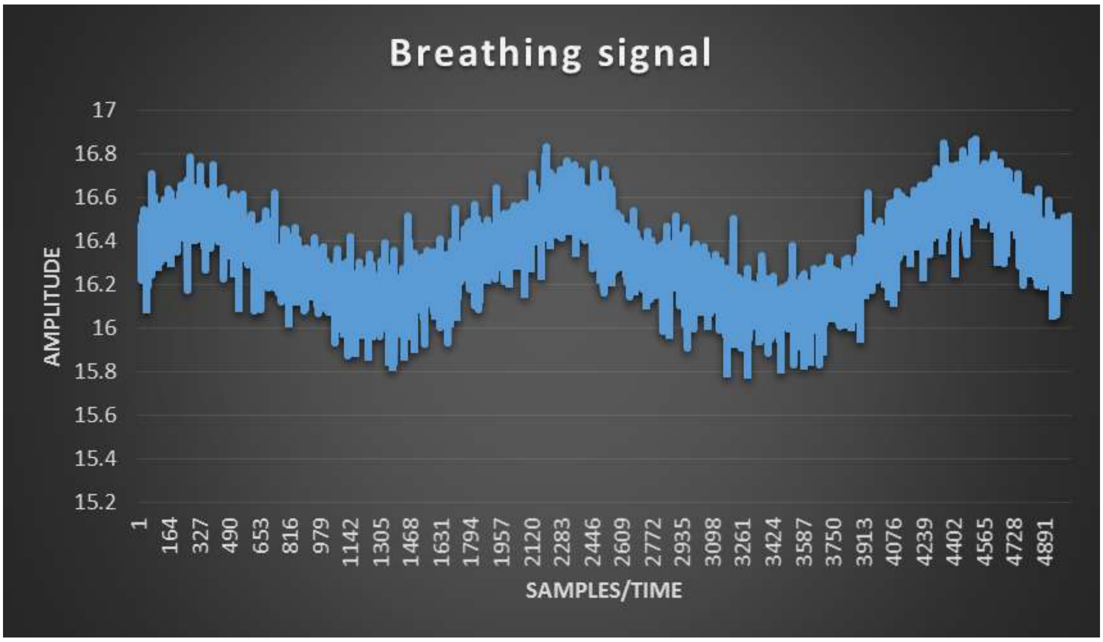

Figure 2. A sample collected raw breathing signal

2.2. Data processing

The collected thermal based breathing should be processed through various stages as shown in figure 3 to derive time series of instant RR. Initially to remove the offset of breathing signal we have to design a digital filter with the help of pole-zero concepts that can remove a DC offset. The transfer function of that equation is shown in equation 2.

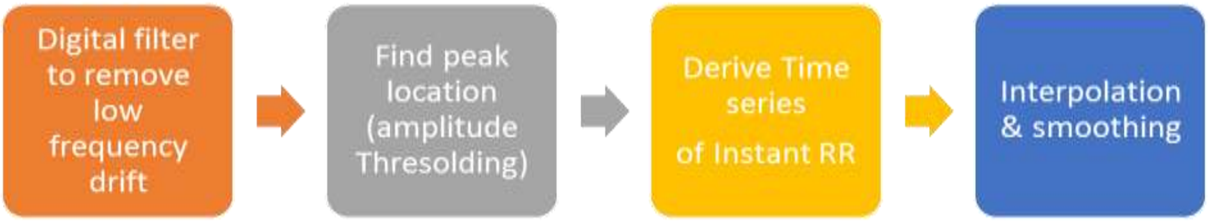

Figure 3. Detail stages of signal processing

$$H(Z) = \frac{1}{T}\frac{[Z-1]}{[z-0.995]} \tag{02}$$

To derive instant respiration rate, it is necessary to find peak location for that amplitude thresholding used. Once the information of every peak locations is available, RR can be derived with the help of equation 3.

$$Instant\ RR = \frac{60}{\text{time distance between to consecutive peaks}} \tag{03}$$

Due to chances of missing any peak or consider any noise as signal peak may generate a sharp peak in instant RR series. This can be removed with the help of interpolation of signals. In this techniques, if an absolute change of two consecutive samples of instant RR is more than 5 RR than we have replaced next RR value with an average of both consecutive values of RR. And at the last smoothing operation [4] perform on the processed signals of window size 20 represented in equation 4.

$$y(n) = \sum_{k=0}^{N} b_k x(n-k) \tag{04}$$

Where b_k are coefficients of filter and N is the order of moving average (smoothing) filter.

2.3. System Modelling

All systems of a human body are nonlinear and interconnected with each other. To implement a nonlinear complex system always an artificial neural network is preferable. Here Concept of the artificial neural network is used to predict single and multi-step ahead prediction of respiration rate. Single step ahead prediction can be described by nonlinear function F as per equation 5.

$$y(n+1) = F\big(y(n), y(n-1), y(n-2), y(n-3) \ldots \ldots y(n-p)\big) + e(n) \tag{05}$$

Where future value y (n+1) can be predicted from past p samples, where P represent the Autoregressive order and e (n) is residual. Similarly, the function of m steps ahead prediction can be described as equation 6.

$$y(n+m) = F\big(y(n), y(n-1), y(n-2), y(n-3) \ldots \ldots y(n-p)\big) + e(n) \tag{06}$$

The neural network is a collection of interconnected elements that are first trained to perform a predefined task and later it can be tested to unknown inputs. Performance of neural network depends on a number of hidden layers, a number of neurons in each layer, the structure of network, training datasets, the algorithm used to adjust weights and activation function of neurons. In general time series prediction kind of application only past response is available and past values used to predict future. In such a case always nonlinear autoregressive neural structure is preferable. Here for our application, we have used NARNET with a single hidden layer who has 10 neurons and a number of inputs (previous values) 30 selected shown in figure 4. The activation function for neuron of hidden layers is tan-sigmoid and for output neuron, it is a linear function.

In this work, all subjects selected for the test are normal and young, they run up to 3 stages of BRUCE protocol. Out of this 9 min, we have divided 7 min dataset for the training of neural network and last 2 min for validation purpose. For training purpose here levenberg-Marquardt backpropagation algorithm used that optimized weight and bias values. During training, a dataset of instant RR up to 7 min are divided differently for single and multi-step ahead prediction. For example for 5 step, ahead prediction y (n+5) is the reference output and y (n)…..y (n-30) past output feedback to the input of the network, in between bias and weight are adjusted with the help of optimization algorithm.

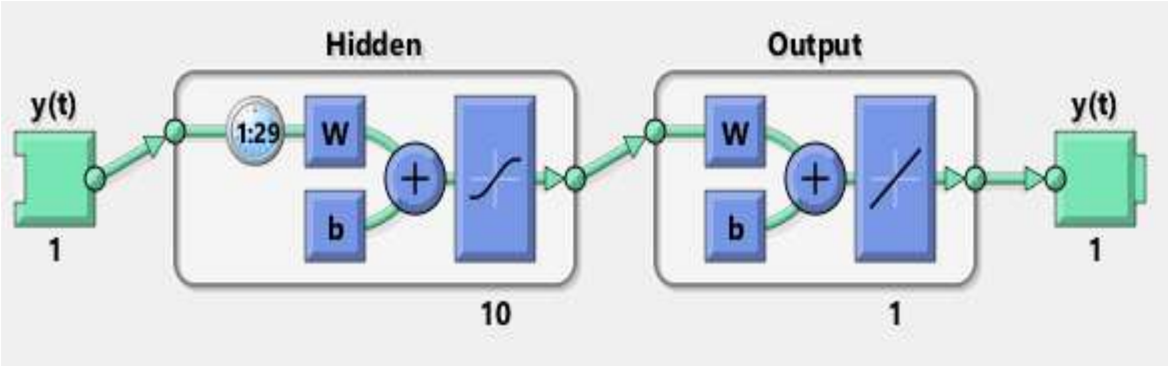

Figure 4. Structure of nonlinear autoregressive neural network

2.4. Validation

Once the neural network is trained, the same model is used for single step and 5 step ahead prediction. To check the performance of the network, predicted response is compared with an actual response (8th and 9th minute). Here we have used root mean squared error (RMSE) because error value is on the same scale of the signal and it is advisable for time series forecasting [5].

III. EXPERIMENTAL RESULT

This section represents experimental results of NARNET where subjects are young whose age is in between 18 to 32 year, it is summarized in Table 2. As a sample result of database 01 from Table 2 is displayed in figure 5 and 6 for single step and 5 step ahead prediction. In this case, up to 420-second signal is used for training and later 421 sec to 540 sec for validation with predicted data in both single step and 5 step ahead prediction. Root mean square error found for a single step ahead prediction is 0.0934 and for five-step ahead prediction it is 1.3402. It is also true that if the prediction horizon increases then error also parallel increase.

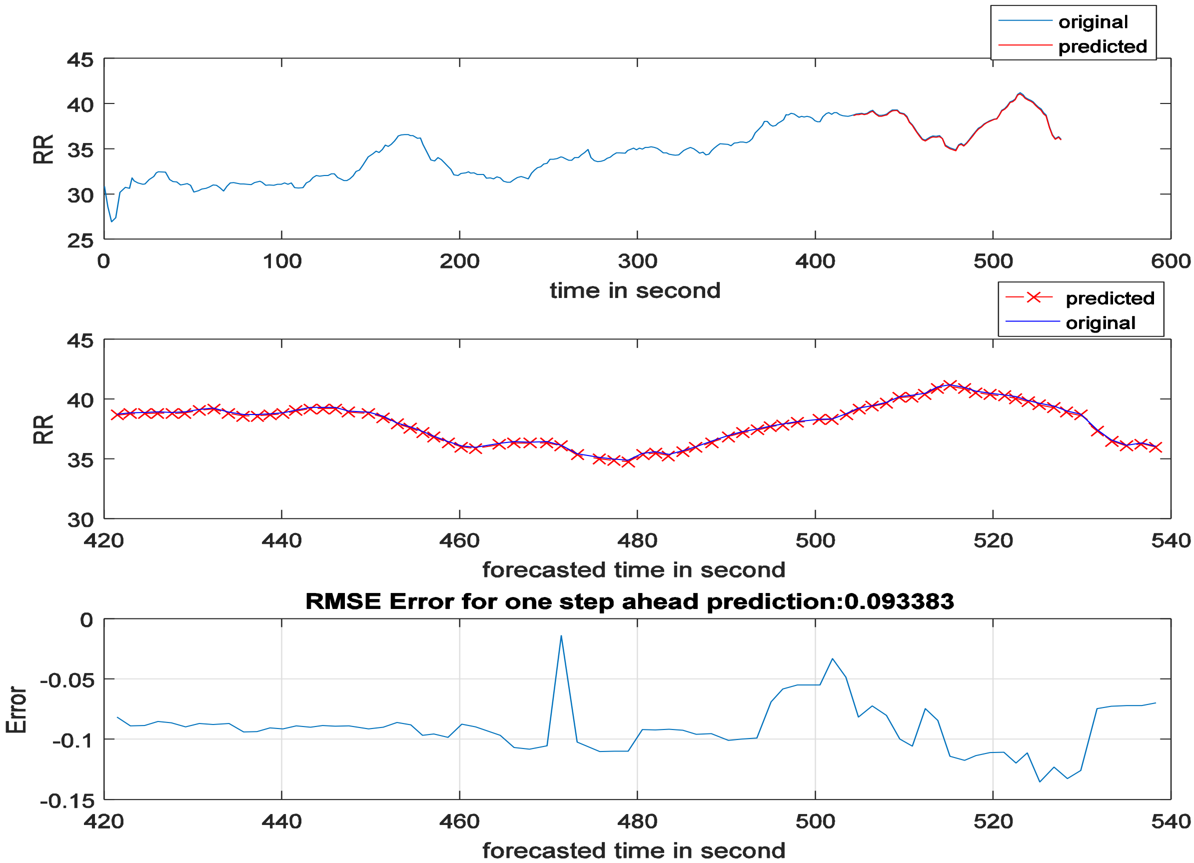

Figure 5. Single step ahead prediction of database 01 (Table 2). Prediction time horizon 421 sec to 540 sec (Middle graph) and Error plot (Bottom)

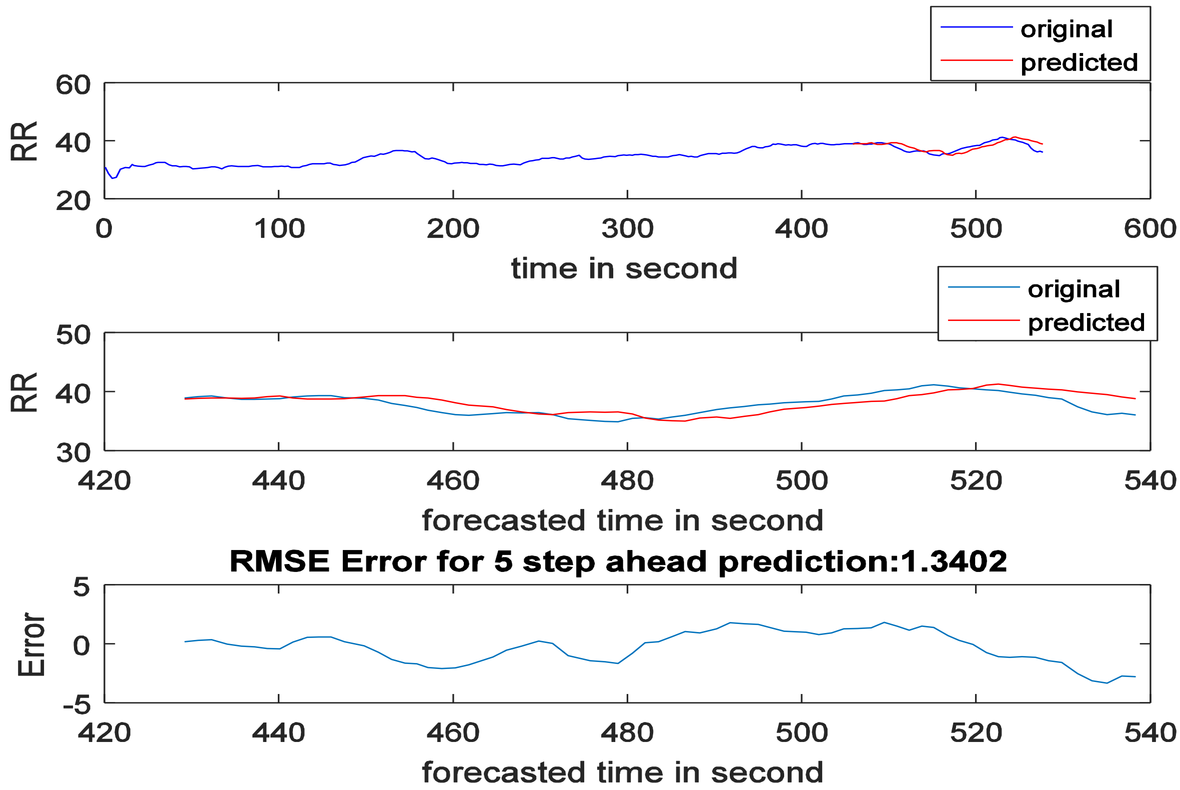

Figure 6. Five step ahead prediction of database 01(Table 2). Prediction time horizon 421 sec to 540 sec (Middle graph) and Error plot (Bottom).

Database	Male/ Female	Age	Instant RR	
			RMSE of single step ahead prediction	RMSE of Five step ahead prediction
1	M	22	0.0934	1.3402
2	M	32	0.4693	0.8333
3	M	29	0.56	1.0145
4	M	22	0.3743	0.5539
5	M	22	0.091	0.9641
6	M	22	0.1019	1.1875
7	F	20	0.1301	1.0352
8	M	21	0.3684	1.4339
9	F	19	0.2171	0.8312
10	M	21	0.24	0.8285
11	F	24	0.1828	0.8856
12	F	18	0.1528	0.7378
13	M	24	0.3368	1.0513
14	F	22	0.2122	0.8454
15	F	22	0.1752	0.7299
16	M	24	0.5288	0.8339
17	M	25	0.1253	2.3407
18	M	24	0.3005	0.5813
19	F	20	0.2504	2.4799

Table 2. Experimental result's summary of single and multi-step ahead prediction of instant RR using NARNET.

IV. PREVIOUS RELATED WORK

Predicting a hidden information in the medical field is always an area of interest. At many places work related prediction in exercised environment found. Maximum workload a human body can sustain can be predicted and it can be helpful for fitness related interpretation. If it is derived with only factual parameters like age, height then result is not fully satisfactory for everyone [6]. It can be derived with the help of a short cycle ergometer test [7], artificial neural network & K-nearest neighbor [8]

A relevant work like RR interval of ECG prediction with ARMAX model [9], Instant RR and Instant HR prediction with Adaptive and ARMAX model [10], prediction of RR intervals of rat with the concept of fuzzy clustering [11], time-varying nonlinear prediction of HRV time series and EEG signals [12] and framework for prediction of HR & VO_2 at the next and final steps [13] found. A huge amount of work relevant to multi-step ahead prediction or time series prediction in other domain found but it is not our area of interest.

V. CONCLUSION

Prediction of future values is always a challenging task and area of interest in many filed. During incremental exercise workload to the cardiopulmonary system is high enough and continuously increasing, it is not always safe for patients. So single step and multi-step ahead prediction of the signal may get an idea about the future condition of health status and helps to avoid a critical situation. As the prediction step increase, the error of prediction also parallels increase. Someone can extend this work for another parameter like heart rate, O_2 or CO_2 concentration in exhaling air and many more. Also, the performance of prediction can be improved with the help of another model.

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