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Comparison of models performance for forecasting of instant Heart Rate and Respiration Rate during incremental exercise

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Abstract:*Cardiopulmonary exercise testing (CPET) is a non-invasive method to evaluate cardiopulmonary system's capacity. It provides fitness relevant & disease preventive information and used for measuring physical fitness of pre-employment & sports persons. In incremental exercise protocol, the level of physical stress increase periodically. So in later stages of incremental exercise, an amount of stress level may overload cardiac functions and create critical situations. This paper proposed two models for forecasting instantaneous values of Heart rate (HR) and Respiration rate (RR) by prematurely ending the test, which reduces physical stress and time of a test. We have implemented two models, which are (1) ARMAX (Auto Regressive Moving average with exogenous input) and (2) Adaptive model. We have tested the performance of models on 20 subjects and comparison of result found that ARMAX model is most suitable for forecasting of instant HR and RR during incremental Exercise.*

Keywords: *Adaptive model, ARMAX model, Bruce protocol, CPET, Forecasting, and Incremental Exercise.*

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I. Introduction

It is possible to derive cardiopulmonary fitness related information by applying variable physical stress, this can be used to measure the fitness of the individual or compare with others, to evaluate continues improvement in health, training prescription and in the medical diagnostic field. Cardiopulmonary exercise testing (CPET) has become an important clinical tool to evaluate exercise capacity and predict outcome related to cardiopulmonary functional capacity. CPET provides an assessment of the integrative exercise responses involving the pulmonary, cardiovascular and skeletal muscle systems, which are not adequately reflected in the measurement of individual organ system function [1]. As physical exercise increase, consumption of O_2 and metabolic waste increase, to satisfy the need, the function of cardiopulmonary system increase up to their aerobic power [2]. In CPET study, choice of parameters and exercise types are selected on the basis of your goal of the study and it is necessary to understand the standards of the use of CPET [3]. Due to that many predefined incremental protocol are preferable for pre-employment testing for example the WFI (wellness fitness initiative) treadmill exercise test is recommended by US national fire protection agency [4], classical Balke treadmill protocol is used for assessment of fitness in military personnel [5]. Generally Naughten protocol is recommended for Tread mill exercise testing in patients with Heart failures [1] and also he has suggested important test termination symptoms like chest pain suggestive of ischaemia, ischemic ECG changes, fall in systolic pressure, loss of coordination, dizziness, signs of respiratory failure, mental confusion and others.

Generally, instruments like Tread mill or cycle ergometry is used for exercise. Cycle ergometer is less expensive and has comparatively less motion of an upper body, so it is convenient to collect body parameters of interest but overall physiological stress apply to a body is less compare to tread mill. Treadmill exercise is more natural and reflects greater overall muscle use in test [1]. Major problem while dealing with treadmill test is motion artifacts in signal acquisition and discomfort during a recording of ventilator parameters. Here we have selected tread mill exercise with Bruce incremental exercise protocol because it is the most commonly used protocol for exercise [6].

Exercised based evolution is a non-invasive method but it is not always safe to test patients at high physical stress like cardiac patients and asthmatic patients. Especially in incremental kind of exercise protocol, physical stress is increased at a specified interval, so in later stages amount of stress to cardiopulmonary systems are high. Heart rate generally reflects response of Heart to exercise or recovery from exercise, so there should be some prediction formula that gives you exercised based target heart rate(THR) for safety purpose. Robergs and Landwehr has presented a survey on different prediction equations for THR [7]. Then in such situation, research like a forecast of future response (Time series of signals) provides facilities to reduce physical effort and allow for saving time with necessary information.

To obtain an accurate forecast of future values we have selected two models, which are ARMAX and Adaptive model. Both models are used for prediction are working on the principle of time series forecasting. So the performance of both models depends on their training with the help of subject's own past response to exercise. Heart rate provides crucial information of the Cardiac system and respiration rate about pulmonary function, that's why we have selected instant HR and RR as our signal of interest. The performance of models is evaluated by comparing actual value with estimated values of future.

The paper is organized as follows, Section-2 Methodology. Section-3 Experimental results & discussions, Section-4 Previous related work and Section-5 Conclusion & Future works.

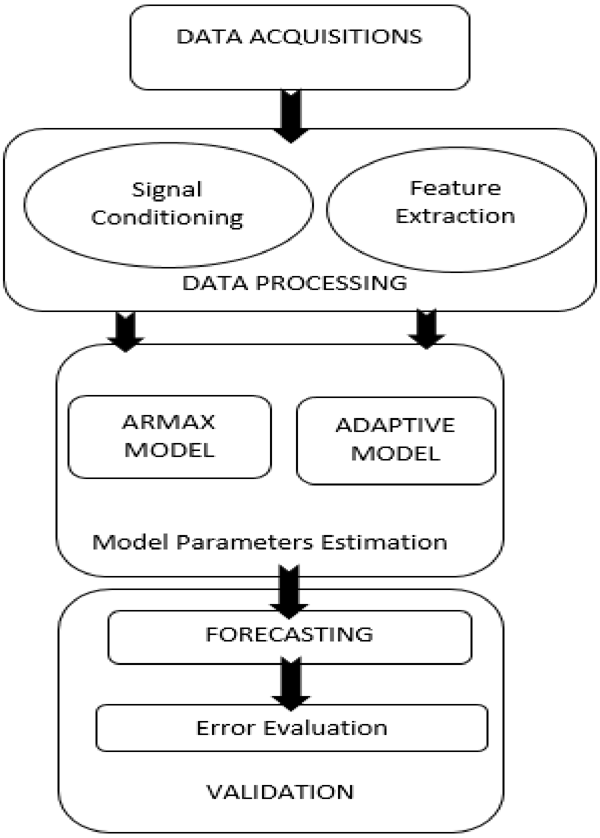

Fig. 1 signal flow diagram of proposed work

II. Methodology

Our proposed work process the collected physiological signals during incremental exercise, which are process through various phases (i) Data acquisition, (ii) Data Processing, (iii) Model parameter Estimations and (iv) Validation. The signal flow diagrams are shown in Fig 1 and details are discussed below.

2.1 Data Acquisitions

Here we have used tread mill instruments with BRUCE protocol for the incremental exercise test. In Bruce protocol each stage has 3min time step and as the stages increase physical stress increase in the combination of treadmill speed and incline. During a test, physiological signals like ECG and breathing signals are continuously monitored for 9 minutes (3 stage of a protocol). Set of surface electrodes are used to collect ECG continuously and a thermistor for breathing signal. Thermistor placed near to nose with the help of mask can easily sense a temperature change of inhaling and exhaling air. Subjects used over here for data collections are normal and quite young.

2.2 Data Processing

First Collected physiological signals are samples at 1 kHz sampling frequency. The main challenging task for us when dealing with exercise condition is the noise level, motion artifacts, and signal trends. To overcome above, ECG signal initially processed through band pass filter (5 to 15Hz 2^{nd} order butter worth filter), and various stages of PAM TOMPKINS algorithm [8][9] for detecting a location of R peak , later it is converted to time series of instant value of Heart rate by calculating time between two consecutive R peaks. Breathing signal recorded with the help of thermistor are quite good in quality so it is process through moving average smoothing filter [9] and later, we have derived time series of instant Respiration rate by detecting time distance between two peaks of temperature based breathing signal.

2.3 Model Parameters Estimation

Time series forecasting is a method of predicting future values from recorded past values. Always our efforts are for selection of models parameters such that, a minimum error found when comparing the actual response with forecast response.

Both models, (1) ARMAX and (2) Adaptive model, does not require any external database for training or another purpose. These models used past data of subjects for modeling purpose and then the same model is used for forecasting. For this work, out of 9 min data sets, 7 min data is used for model parameter estimation purpose.

In the statistical analysis, ARMAX model can represent a system in term of three polynomials, one for the auto-regression (AR), the second for the moving average (MA) and the third for exogenous inputs terms [10] where ak, bl & ct are corresponding coefficients parameters and P, Q & R are their orders.

$$y_{n=} \sum_{k=1}^{P} a_k \ y_{(n-k)} + \sum_{l=0}^{Q} b_l \ x_{(n-l)} + \sum_{t=0}^{R} c_t \ Z_{(n-t)} \qquad (1)$$

But in a case of a time series of instant HR or RR signals, we have only past database available that's why ARMAX model has only the auto regressive (AR) and exogenous input terms.

The adaptive model has been successfully applied in a variety of fields. The general adaptive model mechanism is depicted in Fig. 2. First, we have applied min-max theorem for data normalization. The adaptive model is nothing but a FIR filter with initially random tap weights. We train the adaptive filter with Ntr samples from the original database of N samples. For example excite the input with sample Xk, Xk-1, …., Xk-n+1, n inputs where k=n….Ntr-1and set reference output as Xk+1. Initially, weights are random so the output of adaptive filter model is not matched with reference output (Xk+1), hence generated error signal is used to adjust the tap weights.

The purpose of adaptive filtering algorithms is to adjust the tap-weight vector of the adaptive filter and minimize the RMSE. We have used LMS (Least Mean Square) algorithm to adjust tap weight vector. The LMS algorithm is based on the method of steepest descent, where the new tap-weight vector w(n+1) is given by the present tap-weight vector w(n) plus a correction proportional to the error e(n) and current input x(n) [11][12].

$$w(n+1) = w(n) + 2\mu \, e(n)x(n) \qquad (2)$$

Where μ is learning rate (0 to 1), this expression is also known as the widrow-Hoff LMS algorithm.

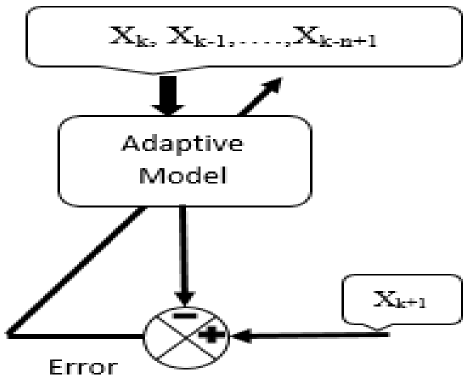

Fig. 2 Adaptive model training concepts

Always in time series forecasting future values are estimated based on past values. A number of past values used for accurate forecasting decide the order of the system. Order of system for which forecasting error is minimum is to be considered for further forecasting. Models are tested for a set of orders like for instant HR, models are tested for 1 to 100 order and similarly for instant RR, models are tested for 1 to 50 order.

2.4 Validation

Once the model parameters are estimated, it is used for forecasting of time series signals (Instant HR & RR). Here we have considered forecasting span of 2 min (8^{th} & 9^{th} min). Forecasting span estimated values of signals are compared with the actual response of the same subject to evaluate the performance of models are evaluated in term of RMSE (Root Mean Square Error).

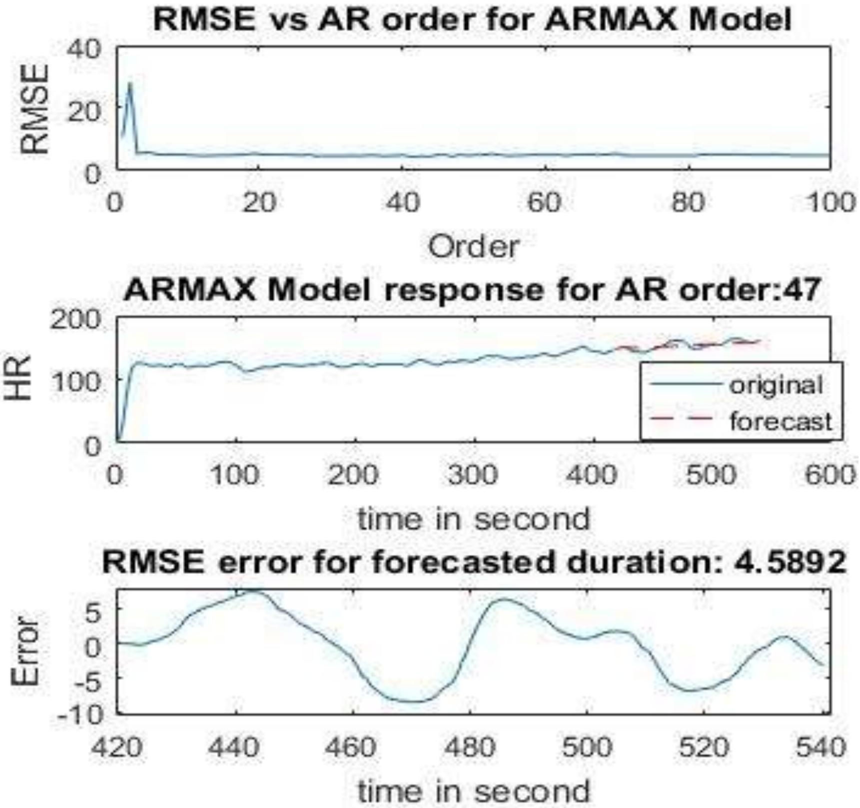

Fig. 3 ARMAX model (database1, For instant HR), RMSE Error vs. AR order range from 1 to 100 (Top Graph), Time series forecasting of instant HR for duration 421 sec to 540 sec & order 47 (Middle Graph), Error plot for forecasted duration (RMSE:4.5892, Bottom graph).

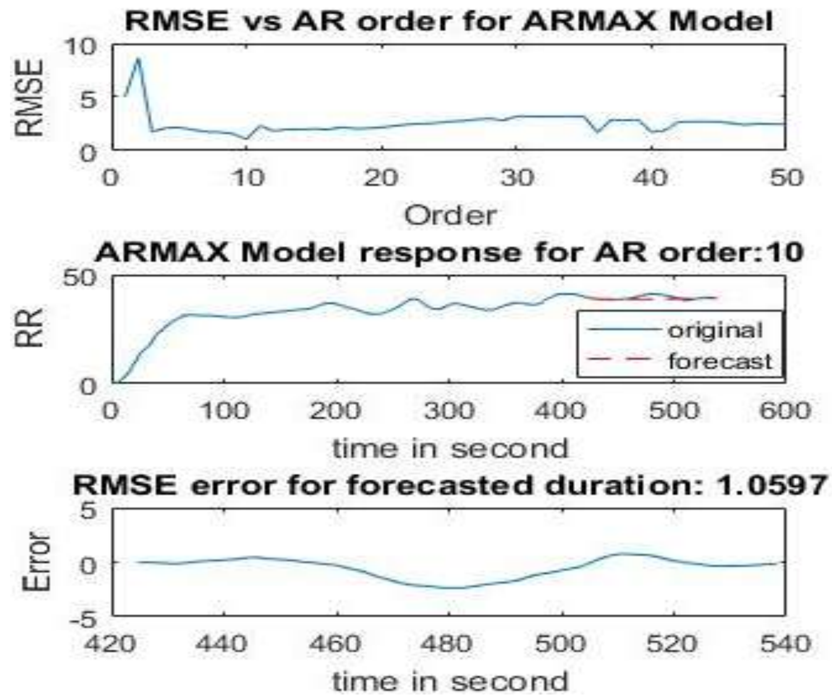

Fig. 4 ARMAX model (database1, For instant RR), RMSE Error vs. AR order range from 1 to 50 (Top Graph), Time series forecasting of instant RR for duration 421 sec to 540 sec & order 10 (Middle Graph), Error plot for forecasted duration (RMSE:1.0597, Bottom graph).

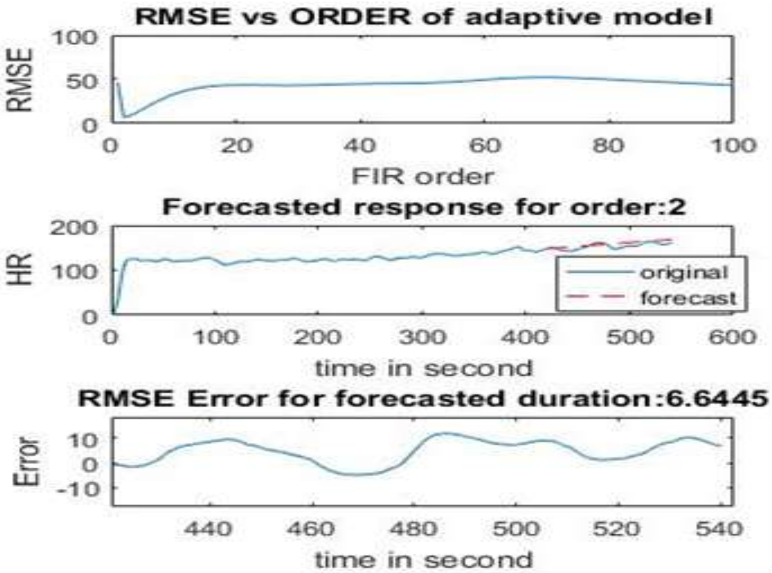

Fig. 5 Adaptive model (database1, For instant HR), RMSE Error vs. AR order range from 1 to 100 (Top Graph), Time series forecasting of instant HR for duration 421 sec to 540 sec & order 02 (Middle Graph), Error plot for forecasted duration (RMSE:6.6445, Bottom graph).

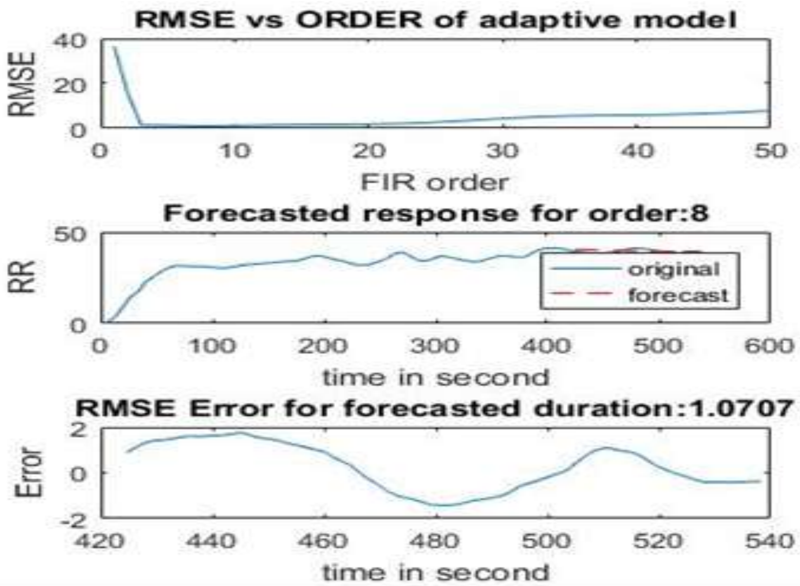

Fig. 6 Adaptive model (database1, For instant RR), RMSE Error vs. AR order range from 1 to 50 (Top Graph), Time series forecasting of instant RR for duration 421 sec to 540 sec & order 08 (Middle Graph), Error plot for forecasted duration (RMSE:1.0707,Bottom graph).

III. Experimental Results

This section presents the experimental forecasting results of both models and their error comparisons. We have derived instant HR and RR from collected database of 9 minutes. Initial 7 minute (420 sec) data are used for parameters estimation of models and then same train models are used for forecasting of later 2 min (421 sec to 540 sec).

Our database is collected from Normal and Young subjects (male & female) whose age is in between 18 to 32 year. As per the above explanation, Models parameter estimation are only depend on their own past data (data of the initial period of the test) so there is no need of any similar database for reference or training purpose like in the case of the neural network. This is the biggest advantage of proposed system.

We have tested both models with 1 to 100 order for Heart rate and 1 to 50 order for Respiration rate. In the case of ARMAX, the order of auto regression and in the case of the Adaptive model, FIR order is considered. And compare their RMSE (Root mean square Error).

As a sample result of ARMAX model for database 1 are discussed here. For database 1, Minimum RMSE error found for forecasted duration is 4.5892 (Order: 47) for instant HR shown in Fig. 3. And similarly, for instant RR, minimum RMSE found for forecasted duration is 1.0597 (Order: 10) as shown in Fig. 4.

Adaptive Model is used in such a way that parameters of FIR filter can be estimated from available past time series of instant HR & RR. Minimum RMSE error found for forecasted duration is 6.6445 (Order: 02) for instant HR shown in Fig. 5. And similarly, for instant RR, min RMSE found for forecasted duration is 1.0707 (Order: 08) as shown in Fig. 6.

We have tested these models on many databases and comparison of results are shown in Table 1.

Data- base No	Age	Male/ Female	ADAPTIVE		ARMAX	
			HR	RR	HR	RR
1	22	M	6.6445(2)	1.0707(08)	4.5892(47)	1.0597(10)
2	32	M	31.8426(02)	0.6357(24)	5.4368(01)	0.6677(11)
3	29	M	5.5278(28)	1.9697(08)	7.1631(19)	3.9133(38)
4	22	M	11.8034(01)	0.9898(49)	1.7391(93)	1.0587(38)
5	22	M	1.5578(06)	1.0372(04)	1.6015(18)	1.2007(50)
6	22	M	1.9134(2)	1.0912(35)	1.8396(32)	1.0437(4)
7	20	F	5.6032(36)	9.1912(49)	6.2254(19)	1.6103(04)
8	21	M	5.1487(12)	1.4472(35)	3.4772(03)	1.0388(05)
9	19	F	9.4926(1)	1.9154(04)	6.9562(24)	1.5652(38)
10	21	M	27.4800(02)	2.7491(05)	5.2945(3)	0.9860(01)
11	24	F	5.7453(49)	4.9701(05)	5.8347(41)	2.2991(01)
12	18	F	1.4279(03)	5.0285(03)	1.5310(36)	3.2301(07)
13	24	M	0.7792(38)	1.6046(05)	0.5981(19)	1.8051(20)
14	23	F	2.1107(4)	0.9006(06)	2.1748(27)	1.9017(20)
15	22	F	19.5621(01)	2.6444(04)	5.8692(08)	1.8224(29)
16	22	F	7.0589(100)	1.6820(06)	6.3337(19)	1.8150(20)
17	24	M	4.9094(20)	1.1787(24)	4.9203(38)	0.7613(03)
18	25	M	20.6825(02)	1.7278(05)	4.1478(05)	1.7084(04)
19	24	M	2.4817(23)	3.4406(32)	2.4215(18)	6.6621(11)
20	20	F	5.5685(77)	2.1280(50)	5.1083(99)	1.8478(16)

Mean	8.86701	2.370125	4.1631	1.899855
Std.Deviation	8.963085567	2.026945866	2.064133683	1.375453041
variance	80.33690288	4.108509545	4.26064786	1.891871067

Table 1 Summary of 20 subject's RMSE Error (and their order) for different models forecasted response (421 seconds to 540 second is forecasted time horizon).

Table 1 represent comparison of 20 subjects response (HR, RR) in form of RMSE error (their order), compare to actual response. And analysis of data shown that variance and Standard deviation are less in case of ARMAX compare to Adaptive model. As per statistical analysis in Table 1, it is prove that ARMAX method is more suitable for prediction of instant HR and Instant RR rate during incremental exercise.

Models are dealing with only instant HR and RR derived from consecutive peak to peak distance from ECG and breathing signal. So execution time also considerably less in both case. In the case of RR, both models take less time compare to HR because repetitive cycle (No. of peaks) in breathing signal is almost 1/3 to 1/4 times of repetitive cycle in ECG. Here we have proven our work in healthy young subjects. But other than sport/fitness one more application is for Cardiac patients and older age range, anyone can address this as expansion of this work.

IV. Previous Related Work

Today various physiological parameters and their changes during exercise play an important role in evaluating the physical condition and it is the current scenario of growing diagnostic field.

At many places work related to CPET is found but it is less relevant to our proposed work. Work founds are relevant to deciding generalized equations for predicting maximum workload [13], a short cycle ergometer test to predict maximum workload and maximum oxygen uptake [14], relation between maximum achievable HR & age [7], morphological change in ECG & PPG due to exercise [15] and various ECG based clinical indexes that represent exercise effects [16]. Baralis has proven that ANN (artificial neural network) give better prediction result compare to K-NN for prediction of the maximum workload from early stages of the test [17]. Research work of Wang has reveals the possibility that cardiovascular fitness related information can be derived from Time constant of heart rate recovery after low intensity and short duration exercise [18]. Baralis have proposed a cardiopulmonary response prediction (CRP) frame work that can predict HRpeak and VO_2peak values reach at the test end and VO_2 value reached the next step but long training time to build the prediction model is a major drawback [19].

Time series prediction techniques is also another option to predict the future value based on its past values. Policker and Geva (2000) have proposed a new algorithm for time series prediction using temporal fuzzy clustering and tested this algorithm on time series representing RR intervals of rats [20]. Another algorithm for time – varying Nonlinear prediction of complex non-stationary biomedical signals has been proposed by Faes [21], This algorithm tested on applicative examples relevant to Heart rate variability (HRV) and EEG signals that are likely to exhibit significant dynamics and/or TV complexity degrees. Another method of nonlinear time series prediction is proposed by German-sallo and Ciufudean [10], the author has performed nonlinear prediction of RR interval in ECG signals with the help of first order discrete wavelet transform and implemented on the artificial neural network based learning structure and compared with ARMA based prediction. And the result showed that ARMA has less error compare to the artificial neural network. But all above work is done for time series forecasting under a normal condition not under exercised condition. Exercised condition has the different set of challenges. Our proposed models can be used to forecast future response from any instant of time during the incremental exercise test. But it is also true that as forecasting time horizon increase, forecasting error also going to increase.

V. Conclusion

This paper present two models for time series forecasting of instant HR and RR during incremental exercise. ARMAX and Adaptive model are implemented such that it forecast future signals from available past data of the same subject. From results, it is proven that ARMAX model is qualitatively most suitable for forecasting instant HR and RR during the incremental exercise test, compare to Adaptive model. This work has very good potential in the direction of noninvasive fitness measurement.

As a future development of this work, anyone can address patient specific study under medical observation or design of new protocol for any specific diagnostic/fitness relevant study

References

[1]. K. Albouaini, M. Egred, A. Alahmar, and D.J. wright, cardiopulmonary exercise testing and its application, *postgraduate Medicine journal, 83*, 2007, 675-682.

[2]. D.A.Burton, K. Stokes and G. M. Hall, Physiological effects of exercise, *continuing Education in Anesthesia, Critical Care & Pain, published on the behalf of the British Journal of Anesthesia,4(6),* 2004, 185-188.

[3]. A. Mezzania. et al., Review Paper Standards for the use of cardiopulmonary exercise testing for the functional evaluation of cardiac patients: a report from the Exercise Physiology Section of the European Association for Cardiovascular Prevention and Rehabilitation, *European Journal of Cardiovascular Prevention and Rehabilitation*, 16(3), 2009, 249-267.

[4]. B.A. Dolezal, D. Barr, D.M. Boland, D.L. smith and C.B. Cooper, Validation of fire fighter WFI treadmill protocol for predicting VO_2max, *oxford university press on behalf of the Society of Occupational Medicine, 65(2),* 2015,143-146.

[5]. S.A.Ward and P. Palange, *Clinical Exercise Testing* (UK, ERS publications Monograph, 2007)

[6]. V.F. Froelicher and J.N. Myers, *Manual of exercise testing* (Philadelphia, Mosby Elsevier publication, 2007)

[7]. R.A. Robergs and R. Landwehr, the Surprising History Of the "HRmax=220-Age" Equation, *Journal of Exercise Physiology online, 5(2),* 2002, 1 -10.

[8]. W.J.Tompkins, *Biomedical Digital Signal Processing (*New Delhi, PHI learning private limited, 2010)

[9]. R. M. Rangayyan, *Biomedical Signal Analysis A case study approach* (Hoboken, John Wiley & Sons, 2012)

[10]. Z. German-sallo and C. Ciufudean, RR interval Prediction in ECG signals, *Proceeding of the IEEE, international conference and Exposition on Electrical and Power Engineering (EPE),* 16-18 October, Iasi, Romania, 2014, 480- 483.

[11]. H. Simon, *adaptive filter theory*, (new Jersey, Prentice-Hall Inc., 1996).

[12]. B. Widrow and S.D. Stearns, *Adaptive signal processing*, (New Jersey, Prentice-Hall Inc., 1985).

[13]. FS Nogueira and FA. Pompeu, Maximal Workload Prediction Models in the Clinical Cardio-pulmonary Effort Test, *Arquivos Brasileiros de Cardiologia, 87(2),* 2006, 137-145.

[14]. F.J.P. Arts, H. Kuipers, A.E. Jeukendrup and W.H.M. Saris, A short cycle Ergometer test to predict Maximum workload and Maximum oxygen Uptake, *International Journals of Sports Med*. 14, 1993, 460-464.

[15]. L. Xu, Y. Zhong et al., ECG and Pulse Variability Analysis for Exercise Evaluation, *Proceedings of the IEEE international conference on Automation and Logistics (ICAL),* Chongqing, China, 2011, 52-57.

[16]. Garcia, J., et al. (2000) 'Comparison of ECG Based Clinical Indexes during Exercise Test', Proceedings of the IEEE conference, computers in cardiology, September, Cambridge, MA, USA, Vol. 27, pp. 833-836.

[17]. E. Baralis, T. Cerquitelli, S. Chiusano and V. D'elia, Early Prediction of the Highest Workload in Incremental Cardiopulmonary Tests, *ACM Transactions on Intelligent Systems and Technology, 4(4)*, article 70, 2013, 70:1-70:20.

[18]. L. Wang, S.W. Su and B.G. Celler, Time constant of heart rate recovery after low level exercise as a useful measure of cardiovascular fitness, *Proceedings of the 28th IEEE, EMBS annual international conference,* New York City, USA, 2006, 1799-1802.

[19]. E. Baralis et al., Predicting cardiopulmonary response to incremental exercise test, *proceeding of the IEEE 28th international symposium on computer-based medical systems*, Brazil, 2015,135-140.

[20]. S. Policker and A.B. Geva, A new algorithm for time series Prediction by Temporal fuzzy clustering, *Proceeding of the IEEE, 15th international conference on pattern recognition,* Barcelona, Spain, 2000, 728-731.

[21]. L. Faes, Ki H. Chon and G. Nollo, Method for time-varying Nonlinear Prediction of complex Nonstationary Biomedical Signals, *IEEE transaction on Biomedical Engineering,56(2),*2009, 205-209.

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