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Design of Efficient Low Pass Infinite Impulse Response Filter Using Dynamic Regional Harmony Search Algorithm with Opposition and Local Learning and Comparison with Harmony Search Algorithm

E. Rasi[1]; Dr.P. Nirmala[2*]

[1]Research Scholar, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.

[1]edagottirasi17@saveetha.com

[2*]Project Guide, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamilnadu, India.

[2*]nirmalap.sse@saveetha.com

Abstract

Aim: *The study aims to design an optimal digital IIR filter for the minimization of ripples in the frequency response of Low pass IIR filter*

Methods & Materials: *Dynamic Regional Harmony Search Algorithm with opposition & local learning DRHS-OLL method is used for the optimal design of efficient infinite impulse response [IIR] due to presence of the premature convergence in Harmony Search algorithm.*

Results: *DRHS-OLL algorithm has reduced the ripples in both passband & stop band regions of low pass IIR filter. The frequency response of the low pass filter also reached the ideal state when compared to the Harmony Search Algorithm. There is statistical significance difference between DRHS-OLL & HS algorithms where $p<0.05$ (Independent sample test). The mean gain of DRHS-OLL is 13.5873+/-1dB which is better than the mean gain of HS i.e., 5.7433+/-1dB.*

Conclusion: *The performances conclude that the DRHS-OLL algorithm has better gain & reduced ripples when compared to HS algorithm.*

Key-words: DRHS-OLL Algorithm HS Algorithm, Evolutionary optimization, Digital IIR Filter, Premature Convergence, Stagnation, Innovative Digital Filter, Digital Signal Processing.

1. Introduction

Bandwidth Adaptive Harmony Search [BAHS] is the algorithm used for designing the IIR filter compared to the performance of Taguchi Immune Algorithm [TIA] (Ghosh et al. 2009). This is proposed to develop the musician bandwidth features. Design of one-dimensional IIR filters with proper stability has been carried out in this work. Proposed algorithm reduced the norm errors approximately & provided better efficiency. This work compares the frequency response & helps in minimizing the maximum ripples in passband & stopband regions of the IIR filter with the TIA algorithm, in which BAHS outperformed it. Evolutionary optimization technique is used for designing of the digital IIR filter using Particle swarm optimization (Serbet, Kaya, and Ozdemir 2017). Best optimization result of the IIR filter is obtained properly by consuming less time because of its convergence with high speed. This is an evolutionary algorithm proposed for finding the best filter coefficients & also results in the magnitude responses of the IIR filter that has been analyzed in the process of testing algorithms. Optimization of digital filters finds application in FPGA in the field of DTV (Z. Ke et al. 2009). Firstly this will help in evolving the application of the digital filters in digital television. Later it will help in designing the IIR filter by the use of the FPGA which provides the results with the best stability of the IIR filter with high speed performance. It also checks the performances like power consumption, flexibility of the signal which helps in the use of applications like DTV. Butterworth IIR filter is used in the applications in finding the heart rate by using the PPG based algorithm along with the savitzky-golay FIR filter (Chatterjee and Roy 2018). Monitoring of heart rate is the essential task in which IIR & FIR filters produce the appropriate heart responses display. For this PPG signal attenuation should contain better accuracy.

Design of the gravitational search algorithm with wavelet mutation is used for the designing of the 8^{th}order IIR filter (Saha et al. 2015). This algorithm helps for multimodal problems to exploit betterly which helps in limiting the ripples in the pass & stop band regions of IIR filters. The optimization procedure proposed in the paper for digital filters i.e., the IIR filter compared with the FIR using Ant Colony Optimization[ACO] technique (Loubna, Bachir, and Izeddine 2018). In this work computing the applications of ACO of two variants as Ant System & Ant Colony System for different types of optimization of IIR filter. This work also compares the performance of the proposed algorithm along with two different system algorithms for IIR filter optimization. Evolution of algorithm for IIR digital filter design using analysis of swarm intelligence & evolutionary computation technique (Mohammadi and Zahiri 2016). In filter optimization the proposed algorithms are based on artificial intelligence. In the filter designing process the global optimization is used for reducing the filter responses.. All the analysed performances like reliability, mean square error and ios are compared between Swarm Intelligence (SI) and Evolutionary Computation (EC) algorithms. An updated version technique is developed for the optimization of the IIR filter using the improved chaotic harmony search algorithm (Shafaati and Mojallali 2018) that has to work with more complexities in the real time operating applications and compared with HS, GA, PSO, PSOW. In any digital signal processing optimization of filters is most efficient. In this paper, designing of the digital IIR filter is done using a differential evolution algorithm compared to a genetic algorithm (Karaboga 2005). The algorithm is used in finding the search for multi-modes in fast convergence, initializing partial values and the use of few control values. This helps in finding performances in terms of the convergence speed. The standard DE algorithm is good compared to the standard GA in terms of its speed of computation.

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S.R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Y. Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

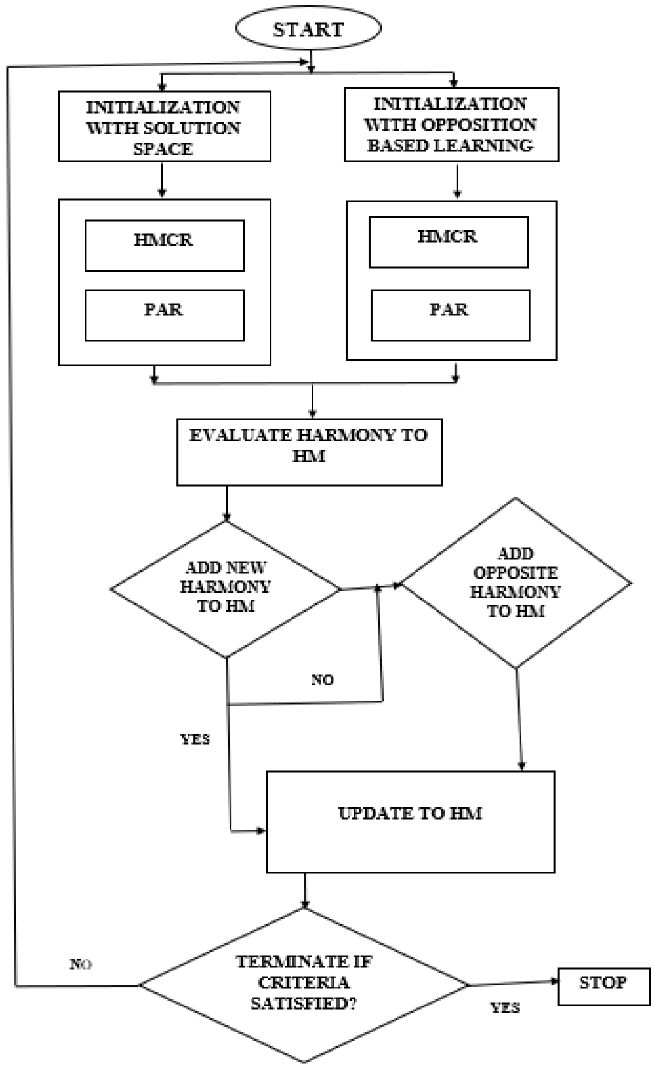
All the algorithms proposed for designing the filter have certain limitations like premature convergence and stagnation in finding the exact solutions in digital signal processing. The aim of this paper is to design an efficient innovative digital filter with frequency response of reduced ripples.

2. Methods & Materials

This project is done in the specialized stream of Electronics & Communication Engineering in Saveetha School of Engineering. Number of groups involved in this project is two. Total number of samples required for the optimization of the Low pass IIR filter is 16 (Ghosh et al. 2009). To improve the significance the sample size is increased from 16-33. The pre-test analysis was done using clinicalc.com by keeping g -power at 80%, threshold at 0.05%, confidence interval at 95%.

DRHS-OLL is the proposed algorithm which is the improvised algorithm of harmony search. This algorithm protects the filter from the risk caused by premature convergence. The DRHS algorithm will depend mostly on the harmony memory & its initialisation. First half of the harmony memory is initialized by the solution space & next is done by the opposition based learning (Qin and Forbes 2011). It helps in splitting the HM memory in different groups & forces each group to create sub-groups for exploiting the solution space efficiently. Later the split HM gets regrouped to prevent premature convergence. (Fig 1). DRHS-OLL algorithm will also limit the stagnation by better memory capacity in regrouping the HM.

Fig 1: Flow chart of DHRS-OLL



The Harmony Search algorithm is the one which develops perfect harmony. In harmony search algorithm memory initialization is done with available harmonies. Because of this, termination of the solution space has been exploited leading to premature convergence. HS cannot optimize the IIR filter with perfect stability. HM also has a limited capacity which leads to stagnation. Due to these reasons, the DRHS-OLL algorithm has been evolved.

The workstation for designing the low pass IIR filter is done in the personal computer in software MATLAB R2019a with all the required add-ons installed. Both the algorithms are simulated using the MATLAB software. The code for DRHS-OLL algorithm and HS algorithm in MATLAB is simulated for optimization. Performance of the optimized low pass IIR filter is shown & values to be noted. The resultant graph shows the ripples are reduced in the DRHS-OLL algorithm.

Statistical analysis is done by the software IBM SPSS Statistics 26. The independent variable is vectors from harmony memory and the dependent variable is gain of the filter. Analysis is done by comparing the magnitude and phase responses of the designed filter with existing filters & even compares the ripples for low pass IIR filter with the Harmony Search.

3. Results

Table 1 - The Magnitude Responses of the Filters for two different Algorithms

S.NO	DRHS-OLL	HS
1	1.9608	1.023
2	4.7812	1.048
3	7.275	1.756
4	9.6611	1.903
5	9.7478	2.618
6	12.278	2.002
7	13.5005	1.465
8	13.5723	0.9854
9	13.8207	0
10	14.2339	0.097
11	14.6849	0.156
12	15.0141	0.765
13	15.1357	1.574
14	15.1313	0.278
15	15.1357	0.029
16	15.1357	0.959
17	15.1356	2.568
18	15.1357	0
19	15.1357	1.982

Table 2 - Magnitude Responses of the Filter

S.NO	DRHS-OLL	HS
20	15.1357	0.38
21	15.1357	10.548
22	15.1357	11.5874
23	15.1357	12.0312
24	15.1357	12.3894
25	15.1357	12.4863
26	15.1357	12.5397
27	15.1357	12.8297
28	15.1357	13.8297
29	15.1357	13.8297
30	15.1357	13.8297
31	15.1357	13.8297
32	15.1357	13.8297
33	15.1357	13.8297

Fig 2 (a) - Frequency responses of the Low pass IIR filter in Dynamic Regional Harmony Search algorithm in which the frequency response of the proposed algorithm is approximately nearer to ideal frequency response & also have the constant gain in both passband and stopband regions

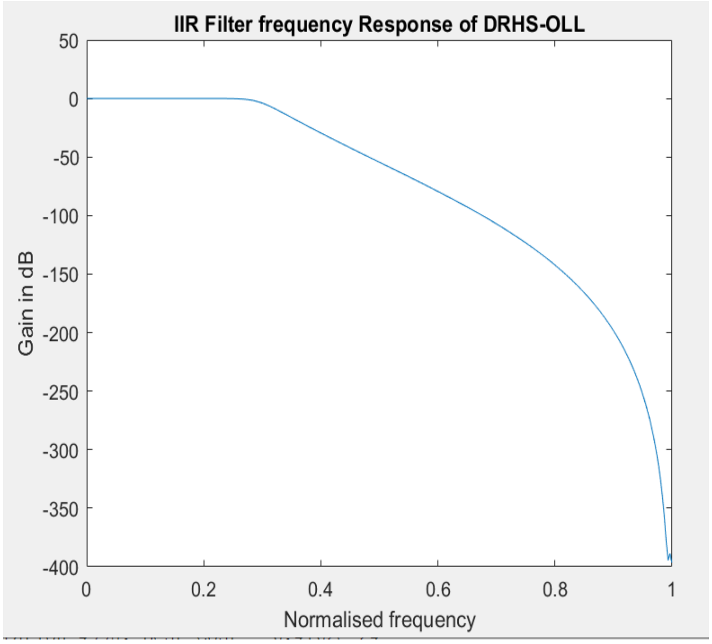
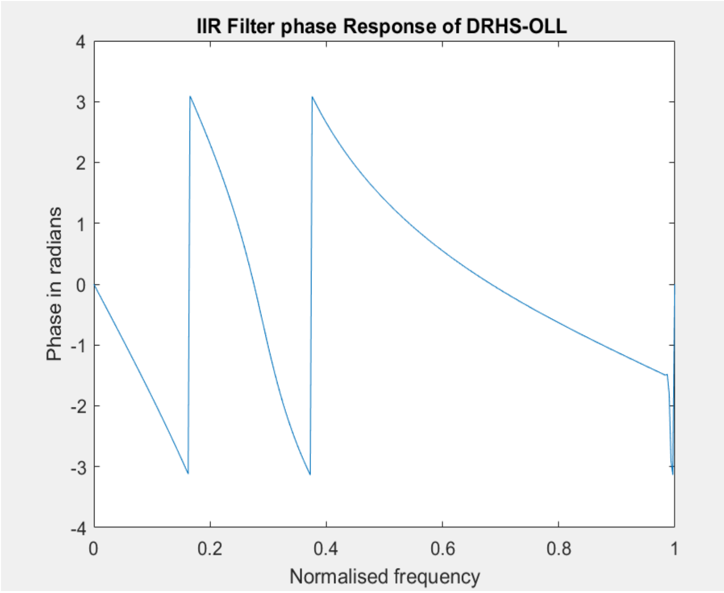


Fig 2 (b) - Phase response of the Low pass IIR filter in Dynamic Regional Harmony Search algorithm



DRHS-OLL algorithm being better when compared to the Harmony Search algorithm, by resultant outputs. (Fig 2). The frequency responses & phase responses of Low pass IIR filter predicts that the proposed algorithm almost provided a distortionless output particularly in the passband of the filter (Fig 2 a & b). The frequency response and phase response of HS algorithms provides (Fig 3 a&b) ripples. (Table 1,2) provides the magnitude response values of low pass IIR filters in both the

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algorithms which provide better gain. The graphical representation of the magnitude response values is shown in (Fig 4 a & b). The comparing values of two algorithms is depicted as a bar graph which shows that the opposition and local learning algorithm is better than the harmony search algorithm (Fig 5). (Table 3) shows the group statistics values with mean, significance, standard error differences between the DRHS-OLL algorithm & HS algorithm. The mean gain value is 13.58dB and that of HS is 5.74dB. There is a significant difference of the two algorithms since $p<0.05$ (independent sample T-test) (Table 4).

Fig. 3 (a) - Frequency responses of the Low pass IIR filter

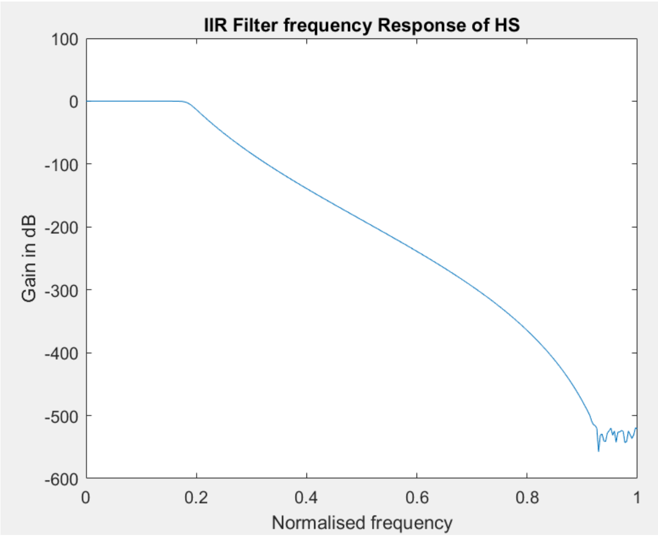

Fig 3 (b) - Phase response of the Low pass IIR filter in Harmony Search algorithm in which the frequency response shows ripples in the stopband region of IIR filter.

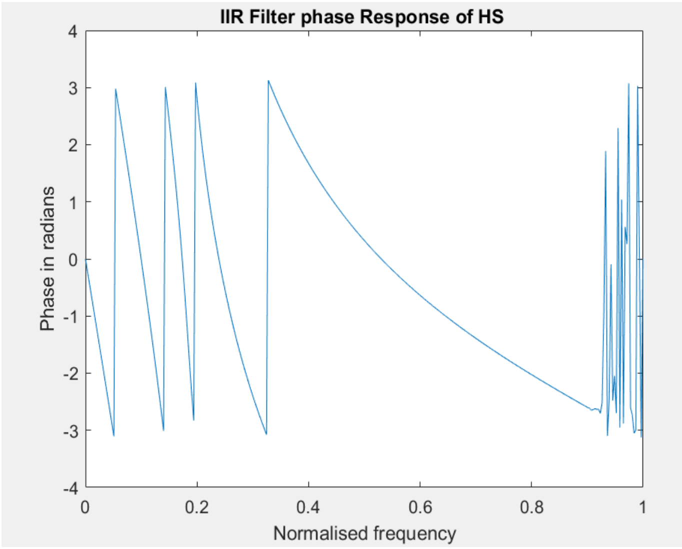

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Fig. 4 (a) - The magnitude responses of Low pass IIR filters in DRHS-OLL

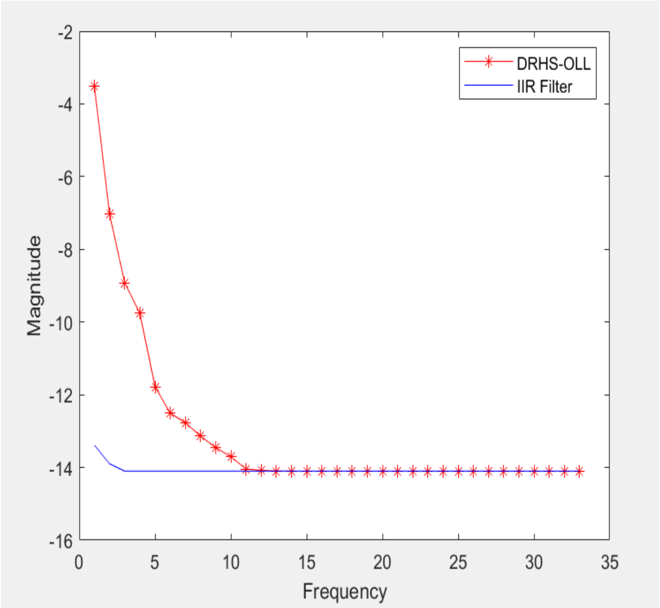

Fig. 4 (b) - The magnitude response of Low pass IIR filter in HS algorithm.

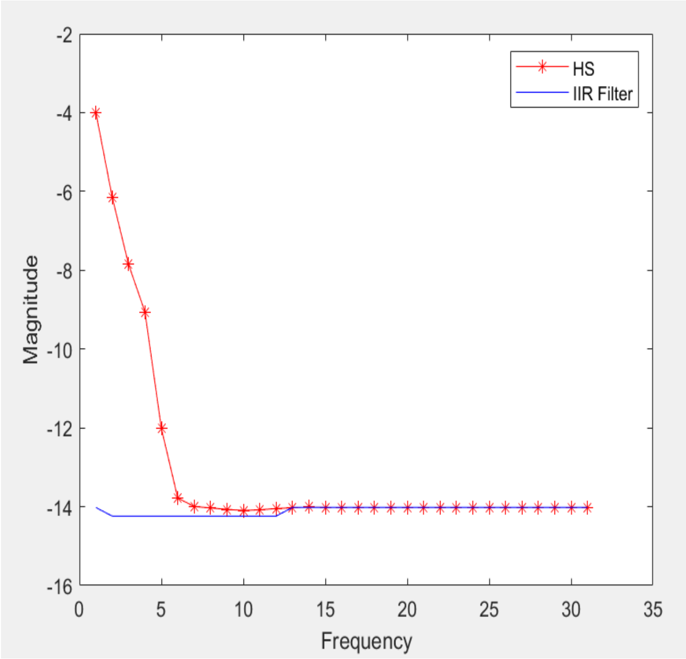

Table 3 - T-test comparison of the DRHS-OLL algorithm with the Harmony Search algorithm. This shows the mean, standard deviation & the standard error mean of the low pass IIR filter compared to both the algorithms.

Parameters	Group	N	Mean	Std. Deviation	Std. Error mean
Gain	DRHS-OLL	33	13.5873	3.25193	.56609
	HS	33	5.7433	5.97566	1.04023

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Fig. 5 - The graphical representation of the low pass IIR filter. Blue colour bars in the graph shows the DRHS-OLL algorithm in which it is compared with the orange coloured bars which are the HS algorithm responses. The graphical representation shows the promising results for the DRHS-OLL algorithm.

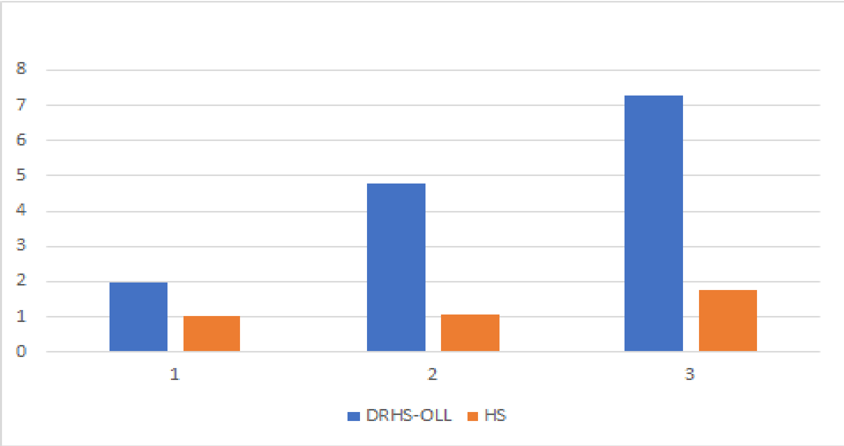
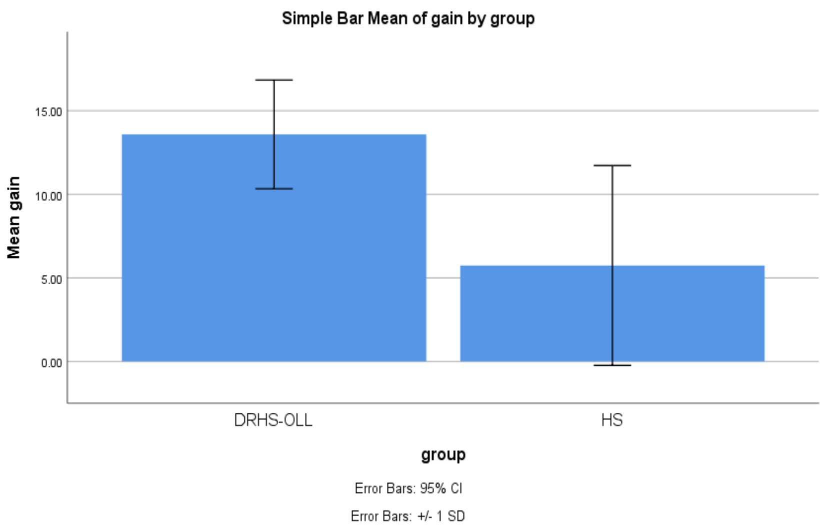


Table 4 - Independent sample test shows the mean, significance, standard error means differences between the DRHS-OLL algorithm & HS algorithm. There is a significance difference of the two algorithms since p<0.05 (independent sample T-test).

Parameters		Leven's test for Equality of variances					T-Test for Equality of means		95% Confidence interval of the difference	
		F	Sig	t	df	sig (2-tailed)	Mean Difference	Std.Error Difference	Lower	Upper
Gain	Equal variances assumed	49.880	.000	6.623	64	.000	7.84398	1.18429	5.47809	10.20986
	Equal variances not assumed			6.623	49.425	.000	7.84398	1.18429	5.46458	10.22337

Fig. 6 - Statistical bar Graph comparing the mean of (+/-1SD) gain of Dynamic regional harmony search with opposition & local learning compared with the Harmony search algorithm. There is a significant difference between the two groups p<0.05 (Independent sample T test).X axis represents DRHS-OLL and HS algorithms and Y axis represents the mean gain.

GGraph



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4. Discussion

In this work it has been observed that the frequency response in Low pass IIR filter is more efficient using dynamic regional harmony search with opposition & local learning than the harmony search algorithm. This study gives p value less than 0.05. Until now researchers have shown that the harmony search algorithm outperformed other evolutionary algorithms. (Ghosh et al. 2009) This study also ensures IIR filter stability by minimizing the norm approximation errors. It also has efficient filter optimization but HS has premature convergence & stagnation. The study also shows that all the filters are considered for optimization due to reduction of errors & suitable for performing regrouping & independent HS of each group along with opposition based harmony creation. (J. Zhang et al. 2006).

DRHS-OLL also has some limitations due to its time consumption. Some researchers proposed other methods apart from evolutionary algorithms. The findings in IIR filter design is based on the New Least Square method used for improving the order of the filter & in filtering efficiency improvement. (T. Zhang and Wan 2018). This work also provides better optimization of the filters when compared to evolutionary methods. Ant Colony Optimization technique is used for showing the stability of the designed filters that has been proved by the position of the poles using optimal coefficients.

Our institution is passionate about high quality evidence based research and has excelled in various fields (Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

The factors that affect the study are pitch adjustment rate, harmony memory size, creating opposite vectors for each harmony. Optimizing the filter is difficult because it is suffering from lack of an efficient balance between exploration & exploitation (Ramezani 2013). Random selection rule is also another factor in this algorithm because it affects the feasible search space performance in final iterations. Limitation of the study is that time consumption in DRHS-OLL algorithm initialization is more since continuous process of initialization occurs until the proper solution space is required. A further study should examine the minimum number of features required in reducing the iteration period with better gain.

5. Conclusion

Dynamic harmony search algorithm with opposition & local learning provides better frequency response than the harmony search & reduces the maximum number of ripples in the frequency response of Low pass IIR filter. Optimizing the filter using opposition and local learning algorithms has a mean gain of 13.58dB compared with harmony search algorithm with a mean gain of 5.7dB.

Declarations

Conflict of interests: No conflict of interest in this manuscript.

Authors Contribution

Author E. Rasi was involved in data collection, data analysis, and manuscript writing. Author Dr.P. Nirmala was involved in conceptualization, data validation, and critical review of manuscript.

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