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***Research paper***



# A Survey of Adaptive Filter Algorithms Used for Noise Cancellation Application

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**Abstract**

Noise component is difficult to predict and controlling completely is impossible. There is lot of research going on in handling noise, where speed, faster convergence, computational complexities, accuracy have been a major concern. In this paper the survey of all approaches are presented in minimizing noise with optimum mean square error (MSE). A new concept of adaptive filter using interval arithmetic is proposed. Using this concept, the rounding and truncation errors are taken care. In interval arithmetic the bound of input and output is calculated. Finding optimum weight is of major concern in adaptive filter. This optimization problem can be solved using interval analysis methods. This makes it applicable in many of the modern day technologies like pattern recognition, machine learning and share market analysis where accuracy is a challenging factor. With the combination neural networks and interval analysis the adaptive filter can be efficiently designed. As interval analysis has two values, the time of execution is increased.

***Keywords***: *noise; LMS; neural networks; machine learning; signal processing; interval arithmetic.*

## 1. Introduction

In any system, the expectation is to see the transmitted or captured signal to be in a form which is almost same as the original signal. However, there is always the component called noise present either in its high frequency or low frequency form. The high frequency noise can be avoided to some extent with the aid of silencers or structures known blockers. The low frequency noise can be filtered with anti-noise wave or feedback system which alters the parameters of the system to keep the noise level at its minimum. Noise is also active and passive, which can be controlled by a active power source or a passive circuit. Even after all such systems and networks in place there is no guarantee the accuracy of the signal at its receiving end. With all of the present technologies or system being in floating point which has the method of rounding off to the nearest integers be its positive or negative there is always a question of its reliability in system which requires accurate results and exact solutions. For example imagine the 0.001 milli second of error in the networks used for launching a satellite, which fails to trigger the module responsible for igniting the engine which in turn fails to make the satellite move, the loss occurred is too much to be compensated in terms of money, manpower and time. One of the solution is interval arithmetic where all mathematical operations are done with a selected bound in the form of [a, b] so we know the bound where the exact solution lies making it an accurate system for today's applications [24-28]. With the signals being a-periodic, random in nature and non-Gaussian, the need of a filter which is efficient, adaptive and accurate is on high demand. Multiple researches have been done in this area most of them implemented in floating point which always has the risk of rounding off errors. Any signal processing system needs filters which is best in its performance and its adaptability to handle the noise component in the signal. Noise is of different types which are avoidable and unavoidable. Thermal noise caused by the movement of the charges in the conductor, the burst noise with sudden increase in their amplitude, transmit-time noise added during the transmission of the signal from the source to the destination, intermodulation noise caused by other signal interfering with the signal under consideration, atmospheric noise with the influence of the atmosphere such as lightning, solar noise added from the other solar system such as the sun, cosmic noise caused by the stars surrounding the planet earth. With different types of noise present it shows the importance of forming a filter which is effective enough in cancelling the most common and avoidable noise components in the signal. Next is the accuracy with which the noise could be filtered. Extracting the original information which is very close to the original signal transmitted by the source. An example of the accuracy in finding the measure of the deepness of an ocean explored by the oceanographer [35-36]. It is by sending sound signal from a ship which is transmitted between multiple objects such as the waves, the vegetation in the ocean, the oceanic rocks etc touches the floor of the ocean and reflected back as an echo. The reflection signal is also a combination of noise the system is in floating point. To find the exact depth the oceanographer has to take multiple readings each of which have rounding off in them and in the final declaration of the depth the mean of the total readings is taken into account, we can the importance for these readings to be accurate in nature which otherwise could deviate the mean of the system from the actual value. In such applications where accuracy and noise cancellation have to go hand in hand, this review of an approach which has interval arithmetic making the system accurate and noise cancellation making its an effective system which can used to many of the application where accuracy is of prime importance. With more researches in this field of interval arithmetic, it could present the future with systems which are more accurate and effective.

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## 2. Block Diagram of Interval Adaptive Filter

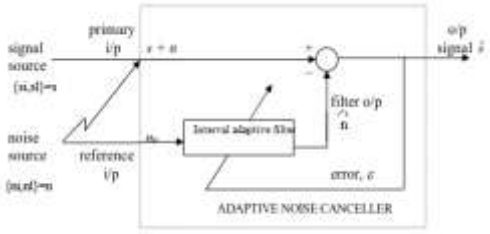


**Fig. 1**: Block diagram for interval based LMS algorithm

The LMS algorithm along with NEURAL networks forms to be one of the best combinations to build networks supporting its application in many of the modern day technologies such as machine learning and artificial intelligence. As shown in Figure 1 the sampled data of any audio signal is given as input to the system these samples, since these input samples carry along with them the noise components, there is a need to filter noise which is removed with the LMS algorithm by tuning and identifying the optimal weights, the samples also are the input to the individual neurons in the NEURAL network the combined operation of the LMS algorithm and the NEURAL networks gives an output which have the noise components at a reduced level making the MSE as minimum as possible with multiple iterations and optimal step size.

## 3. Adaptive filters

### 3.1.LMS Algorithm

Least Mean Square algorithm being one of the core components of this approach all of which have been implemented using the floating point based software. LMS is represent by the following equations where 'w' represent the weights of the system, 'μ' the step size, 'p' the input samples and 'q' the output of the system, 'n' the number of samples, ▼gradient of the system, 'J' Jacobian of the mathematical model.

$$w(n+1) = w(n)-\mu \blacktriangledown J[w(n)] \quad (1)$$

$$q(n) = w^T(n)p(n) \quad (2)$$

$$e(n) = d(n)-q(n) \quad (3)$$

'e' denotes the error signal

'd' difference of the signal between the output and the input of the system [3].

In this algorithm with a constant step size the optimal weights of the system are identified which make the MSE (Mean Square Error) to be the minimum. The approach with floating point in which each of the parametric values are represented with a single value like 'a' or 'x' where the initial iteration is started with an assumption of the initial values for the weights. With trial and error of the initial weights and multiple iterations of the algorithm the optimal values of the weights are calculated, which also have the rounding off errors included in them which accumulate with the increase in the number of iterations. There are multiple variations for this algorithm such as the VSS-LMS (Variable Step Size LMS) as the name indicates the step size is variable and the outcome of the system monitors and adjusts the required signal in which the adjustments are missed could be predicted through formulae [10]. VSS-NLMS (Variable Step Size Normalised Least Mean Square) which was ideal in being stable and having good convergence but computational complexities. FxLMS (Filtered Least Mean Square) in which filter is added in the route of weight update path and the signal used for reference is replaced with the signal from the filter [12]. FULMS (Filtered-U-LMS) in which a neutralizing component which removes noise is added making it an effective fit for the infinite impulse response filters. All filters being stable, have good convergence and computationally simple in few cases, implementing them using INTERVAL arithmetic makes them even more beneficial for the applications needing to be accurate and precise [40]. With INTERVAL arithmetic each of the inputs to the system is given in the form of [a, b] instead of 'a' having bounds set from the initial learning phase of the system, the weights calculated are already optimal with also the bounds having the exact value where the solution exists thus making the system faster in convergence, faster in calculating the optimum values, stability is also achieved much faster.

LMS algorithm with interval analysis has been represented in Figure 1, where 's' is the signal source, 'n' the noise signal, 's' the output signal and 'Ɛ' the error of the system. The input signal with noise is analysed with the LMS algorithm with an initial estimate for the weight which is further increased or decreased depending on the MSE, if the MSE is high the weights are reduced and vice verse to indentify the optiminised weights that give the minimum possible MSE during noise cancellation. Since the filter is implemented with interval analyses and tunes the weights depending on the value of the error, the filter is known as 'interval adaptive filter'.

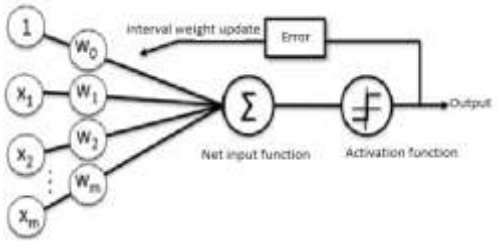


**Fig. 2**: ADALINE framework showing weight auto update with feedback

As shown in Fig 2, with $x_1,x_2\ldots x_m$ showing the signal samples and $W_0,W_1\ldots W_m$ the weights of the signal, which are adaptive in native depending on the error in the system.

## 4. Neural networks

The NEURAL networks work similar to the brain which is initially trained to identify a specific object and that is retained in the memory for the entire lifespan of the human being. So whenever the object is presented to the human it identifies the objects with the name assigned to them like a flower or a ball etc The main factors influencing the network are the nodes which are of input, the activation function, the architecture of the network whether it is single layer or multiple layers, the learning rate.

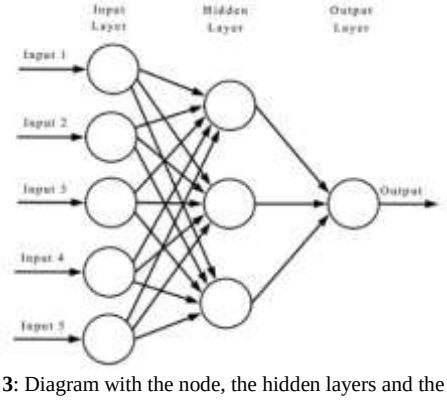


**Fig. 3**: Diagram with the node, the hidden layers and the output

## 5. Suggested approach with neural network

The audio signal that is sampled is given as input to each of the nodes represented by the circles in Fig 3, the nodes has weights and the activation function which in this case is a sigmoid function. The equations same as in equation (1), (2), (3). With the inputs in interval having the maxima and the minima there is a set bound for all the inputs, so the output is the exact solution, the exact interval in which the solution exists. In case the initial estimate of the weights and the step size was in floating point after each and every iteration, the direction in which the optimal weights existed would have much longer time as compared to the INTERVAL approach where the actual bound is known giving a clear idea of the existence of the root thus making the system convergence much faster which otherwise would have taken many iterations.

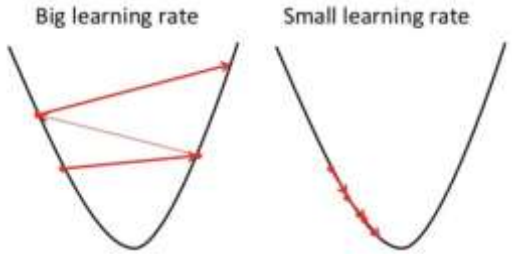


**Fig. 4**: Graph to find the global minima with a large and a short learning rate

## 7. Gradient descent

The main aim of this algorithm is to find the optimal weights of the system which give minimum values of squared errors.The direction in which the operation has to proceed all depend on the initial weights selected, step size and the rate of learning. In case all of these values are in floating point format more of the time would have been in wasted in making the decision to move towards the lesser value or the higher value of the reference value for the present iteration. With the use of INTERVAL the bound for the existence of the solution and the failure of the solution is known with precise values saving the time in making the decision. Also the learning rate used should be optimal enough.

As shown in the Figure 4, if the learning rate is very large the operations may be finding the local minima which may not be the actual global minima, on the contrary of the learning rate is small the convergence of the system is delayed questioning the stability of the system. Such issues are addressed with INTERVAL arithmetic where the bound in the form of [a, b] 'a' minima and 'b' is the maxima give an idea of the direction to proceed further rather than moving round the system in search of the global minima which in turn may not be the actual global minima.

If 'm' is the next position in the direction of the global minima, 'n' the present position, the gamma is the weight and grad (f(a)) is the gradient descent method then the equation is as follows

$$m = n - \gamma \blacktriangledown f(a) \quad (4)$$

As shown in Fig 5 the steps used to find the global minima for the system.

## 6. Noise filtering approach with interval analysis and neural network

A combination of the all the components such as the LMS algorithm and the NEURAL networks for the ADALINE network (ADAptive LINear Element) which forms the system used for effective noise removal and other signal processing applications. The basic requirement for all INTERVAL arithmetic based implementation is a processor with high computing speed.

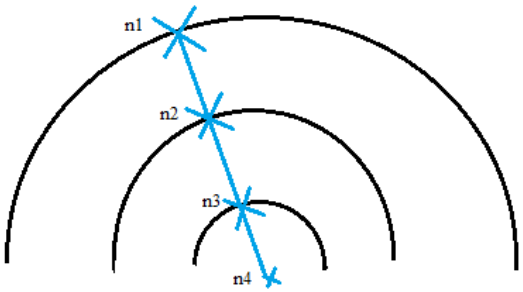


**Fig 5**: Plot of gradient descent with global minima (n4)

In a signal the which could also be represented by a mathematical equation, which may be linear or non-linear we know that the roots lie where the value of f'(x) = 0, with the implementation being in interval arithmetic the initial bound for the root to be existing is assumed based on the nature of the signal, with the boundaries being in opposite directions, further the interval is subdivided into half to find the direction [9] where the root exists and the exact location of the root.

Initial limit being assumed to be [a, b] F{[a, b]}, such that f(a) > 0 and f(b) < 0 such that the exists where f'(x) = 0 and further iterations we consider the midpoint of [a, b]. The initial calculations of the optimized weights is implemented with this approach which forms the basic weights required for building the signal, which also trains the neural network to perceive knowledge required to build the entire signal with minimum error since mean square error (MSE) is made to as minimum as possible by the tuned weights which is the LMS algorithm in the ADALINE [3] network.

The weights obtained from the interval NEWTON method are being given as input to the gradient descent (which defines the level of changes in the output w.r.to changes in the input) which forms the proceeding signal. An approach to find the weights and the output of the signal which has the minimum error similar to the global minima [5]. As the network has initial knowledge of the first few samples of the signal used for training, it tries to identify the global minima resulting in the optimal values, which in turn form the signal with minimum MSE [1], which reduces the error on multiple iterations. The appropriate learning rate [8] and the step size can be identified with multiple iterations. With all the calculations being in INTERVAL it makes the system very accurate in turn aids faster convergence. The summary of significant research done by various researchers is shown in table 1.

## 8. Conclusion

This approach of filtering audio signals with the use of interval arithmetic with the neural network approach improves the efficiency of the filter and enhances the signal processing techniques. The accurate results reduce the MSE but the execution time will be increased. The execution time can be reduced by using GPU's. This kind of noise cancellation can be used, where the applications requires more accuracy. The interval analysis reduces the round off errors after series of mathematical calculations. The combination of interval analysis, neural networks will be future for most of the applications.

**Table 1:** Significant research work in adaptive algorithms

| Sl.No | Title | Model | Results | Remarks |
|---|---|---|---|---|
| 1 | Improvement in the performance of deep neural network model using learning rate, 2017 [15] | Deep NEURAL network with learning rate variation. | Accuracy of the classifier with deep NEURAL network is better than the existing algorithms like Naïve Bayes and Support vector machines. | The accuracy can be even better handled by knowing the right direction of the network with interval arithmetic |
| 2 | Augmented Real-Valued Time-Delay Neural Network for Compensation of Distortions and Impairments in Wireless Transmitters,2018[16] | Complex valued least mean kurtosis algorithm for complex valued system identification, prediction and noise cancellation. | Implementation of this algorithms shows a good increase in the performance of the system for mean square deviation, prediction gain and convergence rate | Complex valued analysis in any system need a bound for the existence of the error which will make the computation complex, with interval arithmetic this task could be managed in an organized manner by bounding the limits for the values calculated. |
| 3 | Finite-Time Passivity-Based Stability Criteria for Delayed Discrete-Time Neural Networks,2018[17] | Propose new weighted summation inequalities for application to finite sum term appearing in the forward difference of a novel Lyapunov–Krasovskii functional. | Delay dependent criterion is proposed with variable delays have been studied new weighted summation inequalities are used to obtain conservative results. | The system is delay dependent which need the accurate time specification for the criterion to be in a stable state. |
| 4 | UCFTS: A Unilateral Coupling Finite-Time Synchronization Scheme for Complex Networks, 2018[18] | Unilateral coupling finite time synchronization method for uncertain complex networks to have improved universality and robustness for the control system | Accurate conditions for the realization of the network synchronization are identified. The uncertain parameters and topological structure can be calculated | Accurate system always has the basic requirement for initiating the system with accurate values, where interval arithmetic forms to be best implementation language that can be used. |
| 5 | Optimizing neural-network learning rate by using a genetic algorithm with per-epoch mutations, 2016[19] | Learning method learning rate optimizing genetic back-propagation with has minimum learning rate and a decrease in the locality of the search. | Learning method is combining the back-propagation and genetic algorithm which makes the learning process less dependent on the properties of the applications making the machine learning process easy. | This method already has high performance and less learning, implementing it with interval arithmetic would make it accurate. |
| 6 | An Augmented Complex-Valued Least-Mean Kurtosis Algorithm for the Filtering of Noncircular Signals,2018[20] | Modeled digital predistorter with augmented real valued time delayed neural network to mitigate the nonlinear distortions in a power amplifier. | Linearization performance of the proposed system for NMSE is better compared to other conventional methods. | Performance can be further improved by identifying the maxima and the minima of the system. |
| 7 | An Inversion Design Method for the Radome Thickness Based on Interval Arithmetic,2018[21] | Novel design method for the possible thickness tolerance interval of the antenna-radome system | Suitable method to determine the feasible radome thickness with its electromagnetic performance filling the requested design performance interval. | Tolerance is the allowable limit to have better performance from the system which could be best implemented using interval arithmetic where each input is given with a maxima and minima setting the bounds at the initial stage. |
| 8 | Application of the interval arithmetic in reliability analysis of distribution system,2012[22] | Interval arithmetic has been used to remove the uncertainty in the accessing parameters for reliable distribution. | Implemented in interval arithmetic have removed the accumulation of errors in the distribution system. | If this analysis was implemented using the floating point approach the actual reliability of the distribution system could be on a debate. |

# References


[1] Wu, Yonghong, Bin Hu, and Zhi-Hong Guan. "Consensus Problems Over Cooperation-Competition Random Switching Networks With Noisy Channels." *IEEE Transactions on Neural Networks and Learning Systems* (2018).

[2] Mengüç, Engin Cemal, and Nurettin Acir. "Kurtosis-Based CRTRL Algorithms for Fully Connected Recurrent Neural Networks." IEEE Transactions on Neural Networks and Learning Systems (2018).

[3] Penthia, Trilochan, et al. "ADALINE based LMS algorithm in a three phase four wire distribution system for power quality enhancement." Power Systems (ICPS), 2016 IEEE 6th International Conference on. IEEE, 2016.

[4] B. Widrow, J. R. Glover, Jr. Mc Cool, J. M. Kaunitz, J. Williams, C. S. Hearn, R. H. Zeidler, J. R. Eugene, Jr. Dong and R. C. Goodlin, "Adaptive Noise Canceling: Principles and Applications", in Proceedings of the IEEE, vol. 63, issue 12, pp. 1692-1716, 1975

[5] Li, Bing, Zidong Wang, and Lifeng Ma. "An Event-Triggered Pinning Control Approach to Synchronization of Discrete-Time Stochastic Complex Dynamical Networks." IEEE Transactions on Neural Networks and Learning Systems (2018).

[6] Saravanakumar, Ramasamy, et al. "Finite-Time Passivity-Based Stability Criteria for Delayed Discrete-Time Neural Networks via New Weighted Summation Inequalities." IEEE Transactions on Neural Networks and Learning Systems(2018).

[7] Wang, Dongming, et al. "Augmented Real-Valued Time-Delay Neural Network for Compensation of Distortions and Impairments in Wireless Transmitters." IEEE transactions on neural networks and learning systems 99 (2018): 1-13.

[8] Han, Min, et al. "UCFTS: A Unilateral Coupling Finite-Time Synchronization Scheme for Complex Networks." IEEE transactions on neural networks and learning systems 99 (2018): 1-14.

[9] Smith, Leslie N. "Cyclical learning rates for training neural networks." Applications of Computer Vision (WACV), 2017 IEEE Winter Conference on. IEEE, 2017.

[10] Li, Yuan-Xin, and Guang-Hong Yang. "Adaptive Neural Control of Pure-Feedback Nonlinear Systems With Event-Triggered Commu-

nications." IEEE Transactions on Neural Networks and Learning Systems (2018).
[11] Gautam, Pooja. "Optimal control of Inverted Pendulum system using ADALINE artificial neural network with LQR." Recent Advances and Innovations in Engineering (ICRAIE), 2016 International Conference on. IEEE, 2016.
[12] Sainath, Tara N., et al. "Multichannel signal processing with deep neural networks for automatic speech recognition." IEEE/ACM Transactions on Audio, Speech, and Language Processing 25.5 (2017): 965-979.
[13] Jueschke, Patrick, and Georg Fischer. "Machine learning using neural networks in digital signal processing for RF transceivers." AFRICON, 2017 IEEE. IEEE, 2017.
[14] Andreas Spanias, "A brief survey of time- and frequency-domain adaptive filters", Information Intelligence Systems & Applications (IISA) 2016 7th International Conference on, pp. 1-7, 2016.
[15] Mao, F. Hu and Q. Hao, "Deep Learning for Intelligent Wireless Networks: A Comprehensive Survey," in *IEEE Communications, 2018*
[16] K. Arora and R. Chauhan, "Improvement in the performance of deep neural network model using learning rate," *2017 Innovations in Power and Advanced Computing Technologies (i-PACT)*, Vellore, 2017
[17] Wang, M. Aziz, M. Helaoui and F. M. Ghannouchi, "Augmented Real-Valued Time-Delay Neural Network for Compensation of Distortions and Impairments in Wireless Transmitters," in *IEEE Transactions on Neural Networks and Learning Systems,2018*
[18] R. Saravanakumar, S. B. Stojanovic, D. D. Radosavljevic, C. K. Ahn and H. R. Karimi, "Finite-Time Passivity-Based Stability Criteria for Delayed Discrete-Time Neural Networks via New Weighted Summation Inequalities," in *IEEE Transactions on Neural Networks and Learning Systems,2018*
[19] M. Han, M. Zhang, T. Qiu and M. Xu, "UCFTS: A Unilateral Coupling Finite-Time Synchronization Scheme for Complex Networks," in *IEEE Transactions on Neural Networks and Learning Systems*,2018
[20] Y. Kanada, "Optimizing neural-network learning rate by using a genetic algorithm with per-epoch mutations," *2016 International Joint Conference on Neural Networks (IJCNN)*, Vancouver, BC, 2016
[21] C. Mengüç and N. Acır, "An Augmented Complex-Valued Least-Mean Kurtosis Algorithm for the Filtering of Noncircular Signals," in *IEEE Transactions on Signal Processing*, 2018
[22] P. Li, W. Xu and D. Yang, "An Inversion Design Method for the Radome Thickness Based on Interval Arithmetic," in *IEEE Antennas and Wireless Propagation Letters*,2018
[23] Z. Zhou, Z. Liu, B. Zeng, Y. Pang and L. He, "Application of the interval arithmetic in reliability analysis of distribution system," *2012 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering*, Chengdu, 2012
[24] Shubra Dixit, Deepak Nagaria, "Design and analysis of cascaded LMS filters for noise cancellation". Springer Science Business Media Newyork 2016.
[25] T.Sunaga, "Theory of an integral algebra and its application to numerical analysis", RAAG Memoirs (1958)29.46
[26] https://dilawarnotes.wordpress.com/2011/04/30/floating-point-arithmetic-disasters/
[27] www.ti3.tu-harburg.de/rump/intlab/
[28] R.E.Moore, R.B. Kearfott and M.J. Cloud, "Introduction to Interval Analysis", SIAM, 2009.
[29] Mitra SK, "Digital signal processing a computer based approach". Mc Graw-Hill, New York, 2010
[30] Widrow B, Stearns SD, "Adaptive signal processing", Prentice Hall, New Jersey, 1985.
[31] Haykin S "Adaptive interval theory". Englewood Cliffs, Prentice Hall, 2012.
[32] Sage AP, Melsa JL, "Estimation theory with applications to communications and control". McGraw Hill, New York, 1997
[33] Akkas, "A Combined Interval and Floating Point Comparator/Selector" Proceedings of the 13th IEEE Conference of Application Specific Architectures and Processors (ASAP), 2002.
[34] D. Jailsingh Nayak and P. S. V. Nataraj "Performance Comparison of a CUDA interval arithmetic library with a standard interval arithmetic library",GPU Centre of Excellence, Systems and Control Engineering Group,IIT Bombay, India-2016
[35] P. M. Farmwald - On the Design of High Performance Digital Arithmetic Circuits PhD. Thesis,Stanford University, 1981.
[36] D. Goldberg - 'What Every Computer Scientist Should Know About Floating Point Arithmetic' ACM Computing Surveys, Vol 32, No 1, 1991.
[37] B. Widrow and M. E. Hoff, Jr. (1960). Adaptive Switching Circuits, Conv. Rec., Part 4, pp. 96, 2004.
[38] B. Hayes - 'A Lucid Interval' American Scientist, Vol. 91, No. 9, 2003.
[39] R. Kirchner, U. Kulisch 'Hardware Support for Interval Arithmetic Reliable Computing', Vol. 12, No. 3, 2006.
[40] P. Kornerup 'Digit Selection for SRT Division and Square Root' IEEE Trans.on Computers, Vol. 54, No. 3, 2005.
[41] U. Kulisch, 'Advanced Arithmetic for the Digital Computers' Springer-Verlag , Vienna, 2002.
[42] A.A. Liddicoat 'High Performance Arithmetic for Division and the elemen-tary Functions - PhD. Thesis', Stanford University, 2002.
[43] S.F. Oberman - 'Floating Point Arithmetic Unit Including an Efficient Close Data Path ' US Patent No. 6094668, AMD,2000.
[44] P.M. Seidel 'On the Design of IEEE Compliant Floating Point Units and Their Quantitative Analysis - PhD. Thesis', University of Saalanden,1999.