At the second stage all intermediate nodes ξ_k are set to zero, except the one with the minimal value. This is implemented via iterative network, where the new value for the node ξ_k is computed via rule 4.

$$\xi_k(i+1) = T(\eta(i), \xi_k(i), \psi_k(i)), \tag{4}$$

where T is a nonlinear function

$$T(a,b,c) = \begin{cases} 0, & \text{if } b-a > 0; \\ b, & \text{if } b-a < 0; \\ c, & \text{otherwise.} \end{cases}$$

and η is the mean of all nonzero intermediate elements ξ_j

If the distribution of the input samples is uniform, the complexity of the iteration algorithm in $O(\log(N))$, ie. after $\log(N)$ iteration steps the value of the output unit η is the median of the input samples.

4. Discussion

The objective of this work was to develop an implementation architecture for the standard median filter to be used in subsymbolic computer vision systems. It is suggested that the first stage of the algorithm is best implemented via analog VLSI design (see figure 3.) and the second by using digital "neural" circuits. Via such a hybrid architecture the real time processing requirements of practical applications could be met.

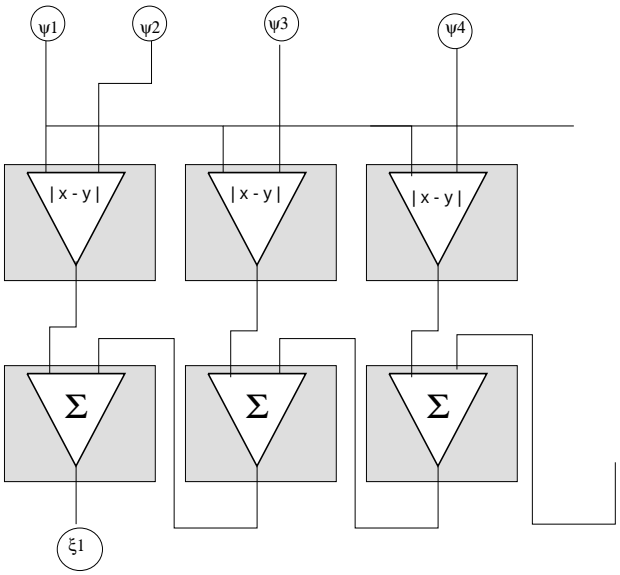

Figure 3. A possible analog implementation for the first stage of the algorithm.

References

Astola, J., Yli-Harja, O., Heinonen, P., Neuvo, Y. (1987). A Class of Edge Preserving Filters Using Logical Operations on Linear Substructures, Proc. Eur. Conf. Cir. Theor. Design ECCTD-87, Paris, France,Sept. pp.609-614

Lindsay, P.H. and Norman D.A. (1977), Human Information Processing, 2nd. Ed., Academic Press.

Tukey, J.W. (1974). Nonlinear (Nonsuperposable) Methods for Smoothing Data, Cong. Rec. EASCON'74, p.673,

2. The standard median filter

Consider a time-continuous input signal $x(t)$. Sampling the input signal at constant time intervals $\triangle t$ gives a time-discrete series of input values $X = (\ldots, X_{i-1}, X_i, X_{i+1}, \ldots)$ at a discrete time step i (at time $t_0 + i\triangle t$). Suppose that we want to smooth the time series giving a smoothed output series $Y = (\ldots, Y_{i-1}, Y_i, Y_{i+1}, \ldots)$ using standard median filter and selecting $2m + 1$ input samples for smoothing. This is defined by

$$Y_i = MED[X_{i-m}, \ldots, X_i, \ldots, X_{i+m}]. \tag{1}$$

The operation $MED[\ldots]$ is equivalent to sorting the input samples X_k into increasing order and taking X_{med} as the centermost sample of the sorted vector. X_{med} is also the solution of the minimization problem

$$minimize \quad S(X_{med}) = \sum_{k=i-m}^{i+m} |X_{med} - X_k|. \tag{2}$$

3. The model

The implementations of the median filters are complicated from the computational point of view, at least when the median filters are compared with the linear filters; see discussion by Astola, Yli-Harja, Heinonen & Neuvo (1987), for example. Different implementation strategies may be used for different applications, the strategy here is to use the median filter as a part of a subsymbolic computer vision system that would be implementable via massively parallel processing.

The network architecture for the median filter is based on a massively parallel implementation of the equation 2. The structure of the network is depicted in figure 2. Computing takes place at two successing stages. First a feed forward network computes $N = 2m + 1$ discrete values $\xi_i = [\xi_1, \xi_2, \ldots, \xi_N]$ of the minimized function $S(X_{med})$, the index of the smallest of these values is also the index of the median input. The second stage is a parallel search to find the index of the smallest value.

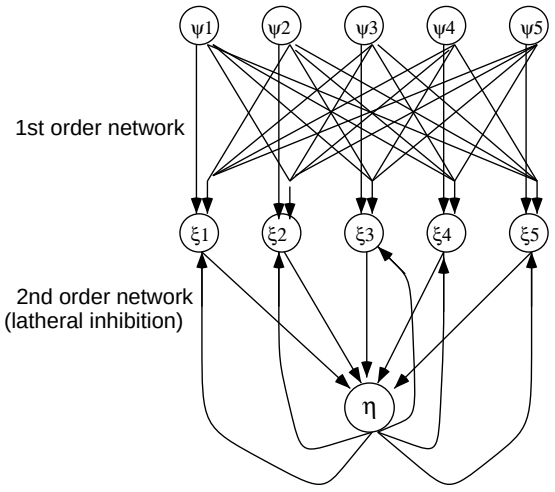

Figure 2. The network architecture for the median filter implementation.

Let the N time discrete samples $(X_{i-m}, \ldots, X_i, \ldots, X_{i+m})$ of the signal be the inputs of the network $\psi_1, \psi_2, \ldots, \psi_N$ at the time step i. The initial values for the nodes at the intermediate layer, $\xi_1, \xi_2, \ldots, \xi_N$, are computed according equation 3.

$$\xi_k(0) = \sum_{j=1}^{N} |\psi_k - \psi_j|. \tag{3}$$

1. An application for the median filter: machine vision

The brain has been a source of inspiration for the recent models in computer vision. The resulting boom of study of neural networks and related developments in computer science have given new insights into how the connections between the real, physical, world and conceptual processing should be combined. Computer vision is one of the most challenging applications for artificial neural networks (ANNs). The task of the computer vision is to introduce information processing capabilities that are comparable to those of humans. The performance of the human visual system is still by far superior to that of the artificial, man-made, systems but by looking some of the properties of the human brain we may get new insights about what features are important and should be implemented in our computer vision systems. It seems that adaptive and massively parallel computing structures with nonlinear mechanisms have such a importance. These structures, however, are too complex to analyse in detail and therefore simple man-made paradigms with similar processing capabilities are required.

Both in computer vision and in human perception edge preserving filtering seems to be vital for low level processing. Figure 1. demonstrates that an image with sharp edges is processed differently than a similar image with smooth edges; the blurred image, image (a), fades if one fixes eyes at the center of the picture. This effect may be a result of a very complex processing in the brain, but nevertheless it is important that edges (in figure 1b.) are preserved at the lowest levels of the visual system. Before edges, lines and other features may be extracted filtering operations must be taken to remove noise from sensory images. The median filter that was first introduced by Tukey (1974) has edge preservation property and it is an elegant choice for man-made vision systems.

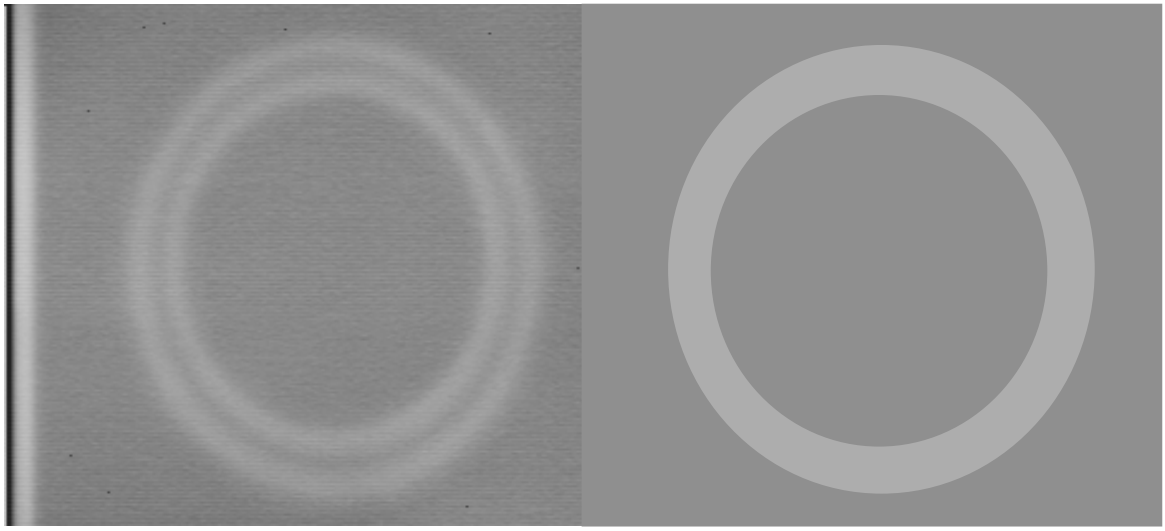

Figure 1. Demonstration of the human edge preservation property, see text. (Figures are reconstructed and modified after Linsday & Norman (1977), where higher quality photos are available).

A SIMPLE "NEURAL" MODEL FOR MEDIAN FILTERING

PASI KOIKKALAINEN

SUMMARY

Nonlinear filters like the median filter have shown their strength in applications but the high computational load excludes them from many real-time problems. The useful characteristics of the median filter are efficient high frequency noise removing capability and edge preservation property. Such properties are important for example in computer vision systems, and it is also known that in human information processing similar effects can be demonstrated. However, the actual neural mechanisms and the median filter are probably different.

The current developments in artificial neural networks (ANNs) has given new possibilities how to implement massively parallel systems via special hardware architectures. In this paper a model that realizes a median filter via neural type of parallel computing is presented. It is suggested that this architecture could be used in connection with a computer vision system that is based on ANNs and implemented on a neural type of hardware.

Keywords: Median filter, Neural networks, Computer vision

Author is with the department of Information Technology, Lappeenranta University of Technology P.O.Box 20, 53851 Lappeenranta, Finland

This work was supported by Tekes Grant

Title:

A SIMPLE "NEURAL" MODEL FOR MEDIAN FILTERING

Authors:

PASI KOIKKALAINEN

Published in:

COGNITIVA-90, MADRID Spain 20-23 Nov. 1990, accepted.

Publications from

THE
INFORMATION PROCESSING LABORATORY

Lappeenranta University of Technology

P.O.BOX 20, SF-53851 Lappeenranta
Finland