Filter Design for Noise Suppression in IVP signals of a Korean-type Total Artificial Heart

*K. S. Om[†], W. W. Choi[†], J. M. Ahn[‡], Y. H. Cho[†], H. C. Kim[‡], and B. G. Min[‡]

*[†]Dept. of Biomedical Engineering, College of Engineering, Seoul National University
[‡]Dept. of Biomedical Engineering, College of Medicine, Seoul National University

Abstract

The removal of impulsive noise terms which occur in interventricular pressure (IVP) signals of a Korean-type total artificial heart is essential for estimation of atrial pressure change. We compared various order statistic filters and conclude that median filter with sidelength $L = 1$ is the most appropriate filter for IVP signals in the perspectives of operation cost, detail preserving (peak value), and waveform.

Notation

IVP : interventricular pressure.
WM : weighted median.
CWM: center weighted median.
L : side length of a filter (full length = $2L+1$).
w : weight of a CWM filter.
Pn : probability that original signals is impulsive noise in a mask.
Pn' : probability that filtered output Y is impulsive noise.
med : median.

I. Introduction

The right and left atrial pressures are important parameters in automatic control of a Korean-type total artificial heart (TAH). During operation of the TAH, the interventricular space's volume is changed dynamically by the difference between the ejection volume of ventricle and the inflow volume of the other. Therefore, the changes in pressure of the interventricular space is related to both atrial pressures. We measure the interventricular pressure (IVP) waveform using a pressure sensor and attempted to indirectly estimate the changes of atrial pressure [1]. As the pressure sensor is attached to TAH, the pressure signal is affected by the movement of TAH. Then the vibration causes impulsive noisy terms in IVP signals.

Nonlinear signal processing is essential for nonlinear signal problems. Impulsive noise like the one occurs in IVP signals is typical nonlinear signal component. Nonlinear signal processing has led to the identification of four major, partially overlapping, families of nonlinear techniques : Order statistics based techniques, polynomial based algorithms, morphological methods, and homomorphic systems [2]. Our approach is order statistics based filters. There were much researches about these filters [3]. But if we trade complexity and precision, the class of CWM filter is a good approach for our purpose of removal impulsive noise terms because of its simple structure and low operation cost.

II. CWM Filter

The weighted median (WM) filter generates $h(j)$ copies of $X(i-j)$ for each $j \in W$. Then the output of a WM filter $Y(i)$ is represented as

$$Y(i) = \text{med}\{\, h(j) \text{ copies of } X(i-j) \mid j \in W \,\}. \quad (1)$$

The WM filter with central weight $h(0) = 2w+1$ and $h(j) = 1$ for each $j \neq 0$ is called the center weighted median (CWM) filter, where w is a non-negative integer [4]. The output $Y(i)$ of the CWM filter is given by

$$Y(i) = \text{med}\{\, X(i-j),\ 2w \text{ copies of } X(i) \mid j \in W \,\}. \quad (2)$$

When $w = 0$, the CWM filter becomes the median filter, so median filter is a special case of a CWM filter. When $2w+1$ is greater than or equal to the window size $2L+1$, it becomes the identity filter (no filtering). Conversely, a CWM filter with a larger central weight performs better in detail preservation but worse in noise suppression than one with a smaller central weight.

III. Filter Design

Before proceeding, we assume the noise signals satisfy the following assumptions.

Assumption 1 : impulsive noise.
Assumption 2 : maximum number of noise terms in the filter window = one.

If the filter window is very small, assumption 2 can be satisfied. For assumption 2 we are going to consider the minimum L (side length of a Filter, full length = $2L+1$). Then we can set the number of noisy terms in the window $Pn \times (2L+1)$ is 1. If we define Pn' to be the probability that filtered output is impulsive noise and Pn to be the probability that original signal is impulsive one, then

$$Pn' = \frac{2w + Pn \times (2L+1)}{2L+1+2w}. \quad (3)$$

For $Pn \times (2L+1) = 1$, $Pn' < 0.5$, and least weight ($w = 1$), Eq. (3) must satisfy $(2+1)/(2L+1+1) < 1/2$. As L is integer, we can see that L must be 2. In this section, we derived a least operation cost CWM filter ($w = 1$, $L = 2$) for IVP signals. In next section, we will compare various filters.

IV. Experimental Results

Fig 1 is the original IVP signals. We can see that there are impulsive noisy terms. Fig 2 is the IVP signals filtered by a CWM filter ($L = 2$, $w = 1$) which was derived in previous section. For comparison we filter the IVP signals by median filter (Fig 3, $L = 2$) and mean filter (Fig 4, $L = 2$). As expected mean filter is too bad to overcome the impulsive noise problem. It is well known that CWM filter is useful detail preserving smoothers and outperform the median filter [4]. CWM filter has higher ability to conserve detailed signal components while removing impulse type noise ones than median filter. Fig 5 and 6 support this property. And the peak value of IVP signals is the most important information for estimation of atrial pressure, so CWM filter is better than median filter for our purpose (peak value of IVP signals). Fig 7 shows that mean filter has not only lower performance of removing noise but also cause the effect of distortion of wave [5]. Next, for lower cost of operation we considered filters with L = 1. In this case CWM filter and median filter have the same structure because w = 0 for L = 1 in CWM filter. Fig 8 is the results of this filter. We can see that median filter with L = 1 is the appropriate filter for IVP signals than CWM filters (L = 2, w = 1 : Fig. 2) and median filter (L = 2 : Fig 3) in the perspectives of operation cost, detail preserving (peak value), and waveform. In CWM filter and median filter, among various operation, comparison one has higher load than other ones, so fast running ordering algorithms is essential [6].

So we conclude that median filter (w = 0) with L = 1 is the most appropriate filter for IVP signals in the CWM filter.

V. Conclusions

We derived a CWM filters for noise suppression in IVP signals, and showed a CWM filter (L = 2, w = 1) will suppress impulsive noisy terms while conserves signals which are not noisy ones. Besides we compared it with mean filter with L = 1, mean filter with L = 2, median filter with L = 1, and median filter with L = 2. And we concluded that median filter with L = 1 is the most appropriate filter for IVP signals in the perspectives of operation cost, detail preservation (peak value), and waveform. Our approach can be applied to other related research project confronted with similar problem.

References

[1] Y. H. Cho *et al*, "Relation between atrial pressures and the interventricular pressure in the moving actuator type total artificial heart," *The 6th Intern. symp. on Artificial Heart & Assist Devices*, 1996.

[2] C. Toumazou , Circuits & Systems Tutorials, *IEEE Intern. Symp. Circuits & Systems*, 1994.

[3] K. S. Om, *A Study on the Development of Digital subtraction Angiographic Image Processing System*, M.S. Dissertation. Department of Electronic Engineering, Inha University, Inchon, Korea, 1996.

[4] S. J. Ko and Y. H. Lee, "Center Weighted Median Filters and Their Applications to Image Enhancement," *IEEE Trans. Circuits and Syst.*, vol. CAS-38, no. 9, Sept. 1991.

[5] Y. H. Lee and A. T. Fam, "An Edge Gradient Enhancing Adaptive Order Statistic Filter," *IEEE Trans. Acoust., Speech, Signal Processing*, vol. ASSP-35, no. 5, pp. 680-695, May, 1987.

[6] I. Pitas, *Digital Image Processing Algorithms*, Prentice-Hall, 1993.

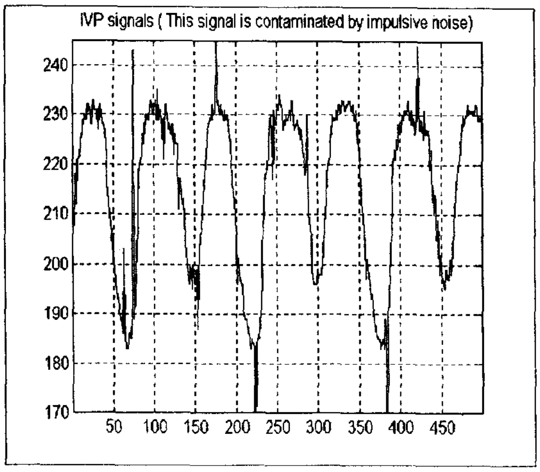

Fig 1 : IVP signals.

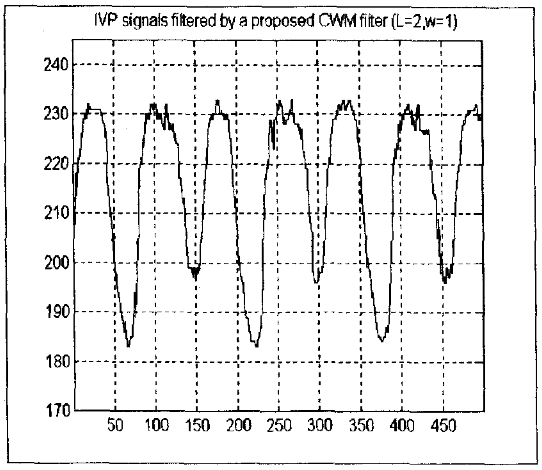

Fig 2 : IVP signals filtered by a CWM filter (L = 2, w = 1).

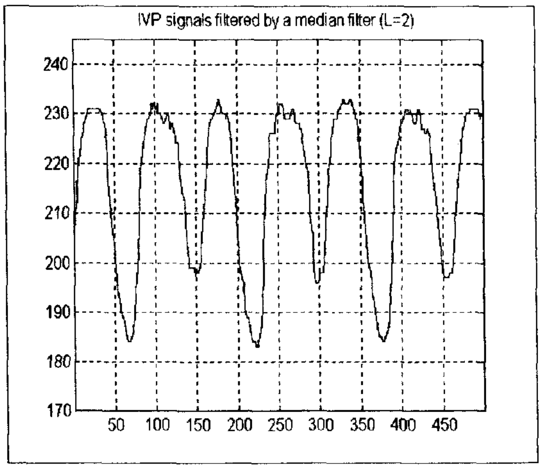

Fig 3 : IVP signals filtered by a median filter (L = 2).

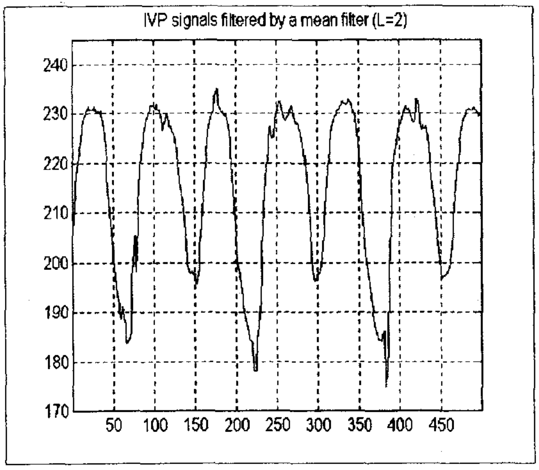

Fig 4 : IVP signals filtered by a mean filter (L = 2).

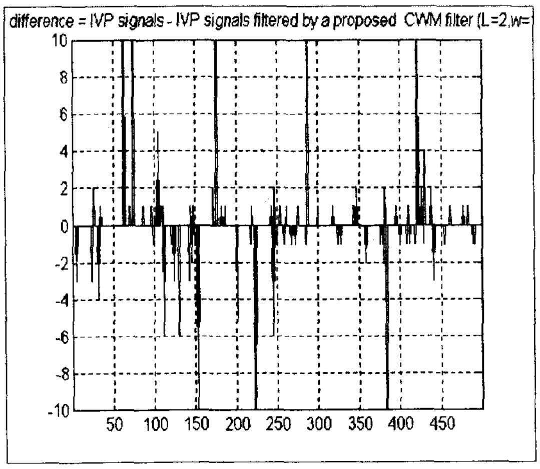

Fig 5 : IVP signals - IVP signals filtered by a CWM filter (L = 2, w = 1).

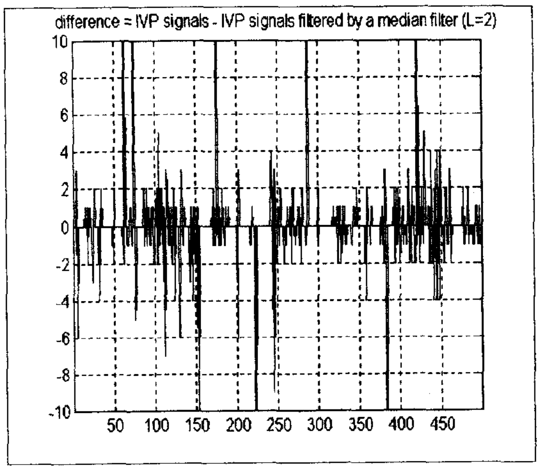

Fig 6 : IVP signals - IVP signals filtered by a median filter (L = 2).

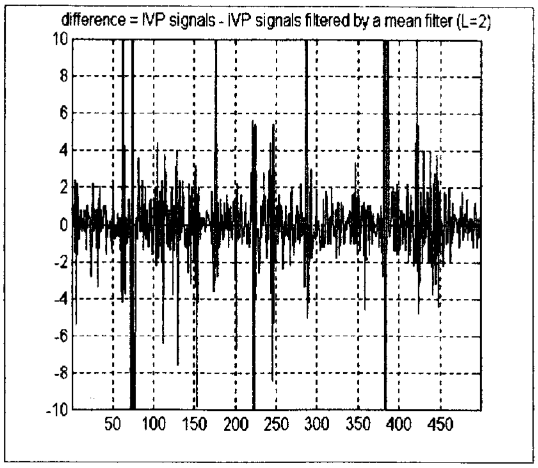

Fig 7 : IVP signals – IVP signals filtered by a mean filter ($L = 2$).

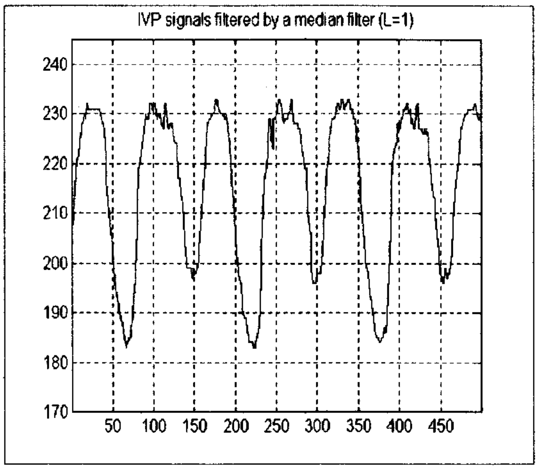

Fig 8 : IVP signals filtered by a median filter ($L = 1$).

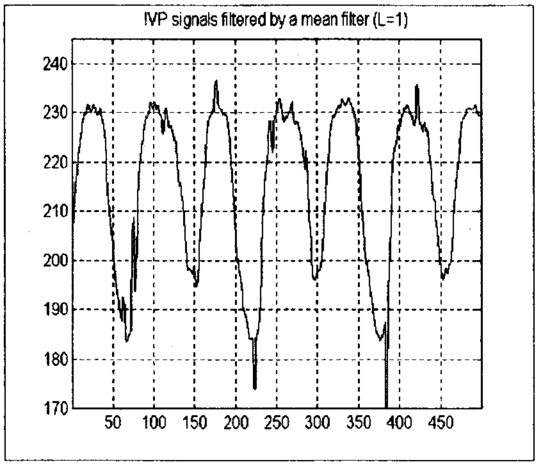

Fig 9 : IVP signals filtered by a mean filter ($L = 1$).