Issues on Medical Image Enhancement

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In this work the problem of medical image enhancement is addressed. Medical images represent a noisy image environment due primarily to the limitations placed on X-ray dose. Data rates in the medical imaging systems can also present the system designer with a formidable task. Typical systems have 8-16 bit pixels, 512x512-2048x2048 image size, and 7.5-30 frames per second. Designing a system to enhance images in real time at these rates requires optimal mask (kernel) size to control costs. The user interface should also allow for adjustment so the radiologists can achieve the preferred image perception.

Classically this enhancement problem has been solved with an unsharp masking technique using a Gaussian kernel shape and various kernel sizes (5x5-64x64). Using Matlab, sets of medical images have been evaluated with various kernel shapes and sizes. The result of the work points toward a maximum kernel size of 15x15 for Gaussian kernel in unsharp masking. To implement the enhancement algorithm a 15x15 image filter in a single chip realization has been completed in Xilinx FPGA (external line buffers). The enhancement algorithm is partitioned into a low pass filter (LPF) and image mixing cores. The Xilinx implementation utilizes the small size of constant coefficient multipliers (KCMs) and uses the fact that both separable kernels are identical.

New cost reduced realizations can now be investigated for medical imaging by reducing the kernel size accordingly. This work also forms a basis for image resizing applications, and noise reduction image filters.

1. Introduction

The enhancement in this study is based on the realization shown in Figure 1. The original image and its blurred version, obtained through a low pass filter, are combined so that the high frequency components of the image is amplified and as a result the perception of the image around edge areas improves. All high frequency components of the image are amplified and the noise in the image will also be inadvertently amplified. This enhancement is shown here by simulation in a one-dimensional case. Addition of high frequency components to the original image will boost the high frequency components by that factor usually 3 to 4 times.

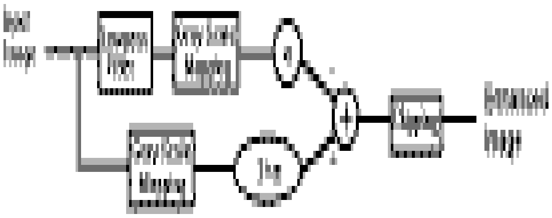


Figure 1 Realization for enhancement.

In the following, first the role of the low pass filter is explained and a particular design procedure is developed. Next, the boosting of high frequency components and final clipping of the gray scale are briefly explained. Finally the hardware implementation, based on Xilinx FPGA's are fully discussed and explained for a medical review station.

2. Low Pass Filter Design

The low pass filter used in image enhancement is mainly intended to generate a blurred image. Weighted difference of the blurred image and the original image results in an amplification of high frequency components and overall enhancement of the image. To improve the perception, the high frequency components of the image are amplified and as a result artificial overshoot/undershoot pulses are produced around edges. A step-like signal is presented in which a relatively wide pulse with non-ideal edges is simulated. This signal is used as the original signal and is compared in all the following simulations to the resultant enhanced signal. The width of the pulse in this signal is large enough so that it is greater than the size of the largest FIR low pass filter used in these simulations. For the effect of the enhancement on short duration pulses a second pulse is used and is small enough so that the smallest FIR low pass filter used in these simulations is larger than the width of the pulse. Finally, for studying the effect of the enhancement on impulsive noise the pulse width is only 2 sample points wide and the transitions, are only one sample point wide.

The first step in processing these signals is to design the low pass filter. Since evaluation of the final perceived result is subjective, it is more reasonable to come up with a set of good low pass filters than fixing one low pass filter as the best choice. One standard approach in designing FIR filters is to use the Fourier design technique. An ideal low pass filter impulse response, with cutoff frequency of f_c, is given in Equation 1.

$$h(n) = \frac{\sin(2n\pi f_c)}{n\pi} \quad (1)$$

Implementation of this filter requires truncation of the filter impulse response, which in general is achieved by using a proper window design. Another approach in designing a low pass FIR filter, is to use running weighted average. A procedure can be developed to generate the weights, filter coefficients, so that a desired edge enhancement can be achieved. A Gaussian function is used to generate different kinds of weights by changing only one parameter. The Gaussian function is given in Equation 2 in which A is the normalizing constant and σ is the controlling parameter that provides the desired weight adjustment.

$$h(n) = Ae^{-n^2/2\sigma^2} \quad (2)$$

Original signals are used with two different filters, namely Hamming and Gaussian. The results of these two cases are shown in Figure 2. The results represented here, are obtained by using 0.1 for the cutoff frequency, which in turn results in inclusion of the several of the side lobes of the ideal impulse response in the filter coefficients. As cutoff frequency decreases the number of coefficients, associated to the side lobes, decreases and the filter impulse response and its performance approaches that of the Gaussian filter.

After careful study of the simulation results the following recommendations are made:

1. When using Fourier design, the coefficients of the low pass filter may include several of the side lobes of the corresponding ideal impulse response (Equation 1). These side lobes will produce a ringing effect on the sides of an edge, which is not desirable in image enhancement. To avoid this inclusion, it is only recommended to use the coefficients resulted from the main lobe of the ideal impulse response. This objective can be achieved by reducing the cutoff frequency and/or the kernel size of the filter.

2. In the case of Gaussian filter design, σ can be adjusted to achieve a desirable magnitude response with all positive filter coefficients. The effective kernel size N_e depends on the desired precision of the filter coefficients. One advantage of using Gaussian filter for enhancement is that, when the kernel size is fixed the filter coefficients can be adjusted by changing only one parameter. This will allow the user to adjust the filter coefficients, within an acceptable range and produce an enhancement that fits his or her subjective judgment.

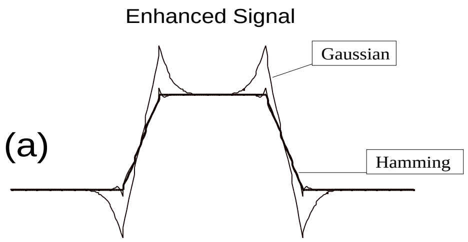
3. From analysis of the overshoot and undershoot pulses around edges, it is observed that the larger the amplitude of these pulses the sharper the slope of the transition becomes. One way to achieve this objective is to use higher boost rate. However, from Gaussian filter design perspective, these overshoot and undershoot pulses become narrower and sharper as σ decreases. The trade off for this reduction is the increase in the filter cutoff frequency, which might reduce the rate of enhancement in slower edges. Another trade off for smaller σ is the results of the filtering on small pulses. In these cases, the good effect is the increase of the height of the pulse. However, as σ decreases, undershoots on the sides of the short pulses will produce an artifact that is comparable with the pulse in size. This phenomenon is completely unacceptable, both in terms of increase in

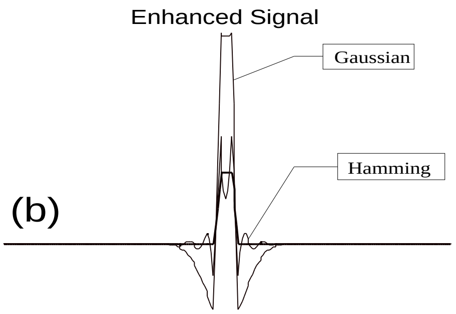
the amplitude and undershoots, if there is some impulsive noise in the image. It is therefore important to apply different σ values and come up with the best compromise in a given circumstance. It is recommended to allow the user to change σ, to come up with his or her best subjective compromise.

4. The kernel size should be large enough so that slow transitions in the image can properly be enhanced. For hardware consideration it should be small enough so that it allows real-time implementation. If the kernel size is originally fixed at an acceptable small size, e.g., size of 7, there will be no flexibility in adjusting the enhancement for individual user by controlling the filter coefficient. If filter coefficients are kept fixed for a system, the best that can be done is to come up with the filter design that is good in average for the images processed by that system and for a typical viewer. But when allowing some flexibility, even if not to the user but to the calibration of the system at each installment, the life of the hardware design will be longer and the design would be applicable to any other future system that might require similar kind of enhancement. Based on many simulations and enhancement of real medical X-ray images, it is recommended to use a kernel size of 15x15. If the kernel size becomes smaller than 15, the best filter for enhancement approaches that of the uniform averaging with less and less flexibility and this will be converted to a simple averaging at about the kernel size of 7. If the kernel size goes beyond 21, the further increase does not provide further advantage to the system. The flexibility achieved by using the kernel size of 15 is sufficient for both system calibration and user adjustment.

3. High Frequency Boost

The effect of high frequency boost is amplification of the amplitude of the overshoot pulses around edges, which affects the perceived sharpness of the image and can be adjusted to the liking of the viewer. It should also be pointed out that when the edge is very close to the limit, 0 in the dark region or L in the bright region, due to the final clipping of the enhanced image, the increase in boost rate has no effect. However, for other edges, the larger the boost rate the more pronounced the edges will appear.





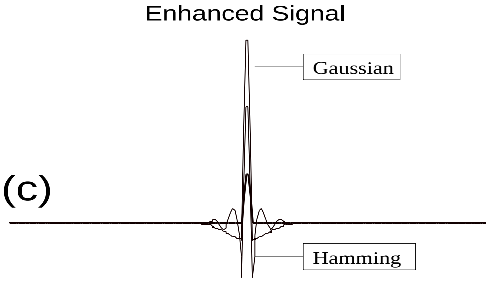


Figure 2 Enhancement of various step-like signals using Hamming filter with 0.1 cutoff frequency and Gaussian filter with σ=10: (a) results on a wide pulse, (b) results on a short pulse, and (c) results on an impulsive noise.

4. *Implementation Details*

The enhancement algorithm developed in the Matlab environment was applied to the problem of a medical image X-ray review station. Loops of images are stored on the local disk after being retrieved from the archival system. These loops are generally in a DICOM (Digital Imaging and Communications in Medicine) format. The medical review station has many functions. The function we will describe here is image review. The workstation transfers the compressed images from the local disk to the PCI board which has the architecture shown in Figure 3.

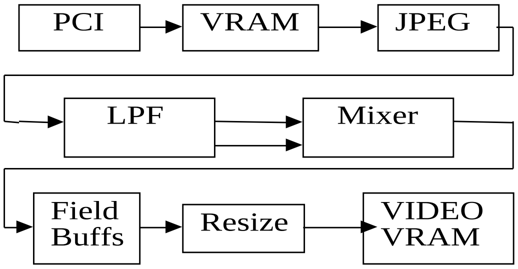


Figure 3 PCI Board Architecture.

In review mode the compressed image data is read from the hard disk into the first VRAM through a Xilinx PCI chip. There are two buffers for the VRAM allowing for continuous operation of 1Kx512 30 frames/s. The JPEG core decompresses the image and sends data to the low pass filter (LPF) Xilinx chip. Once eight lines have been sent to the LPF chip, data moves forward to the mixer Xilinx chip, which performs boosting. The mixer chip also allows for cropping of the image data for a zooming function. The resize portion of the board allows for final image size change before the image data enters the video VRAM.

5. *Filter and Mixer Implementation*

The specifications for the review station are 1Kx512 30 frames/s. With this requirement a data clock of 20 MHz is sufficient. The first stage of the 2D low pass filter takes line data in from the JPEG section and muxes in previous lines so the line buffer memory chips can be used at 40 MHz holding two lines each. Filtering is performed in the vertical direction first with preadds performed as the data comes out of the line buffers on even clock cycle. The vertical data then moves through 8 KCM (constant multipliers) and through the summation tree at 40 MHz. With the vertical filtering performed the data is preadded for horizontal filtering and sent back through the 8 KCMs and summation tree on the odd clock cycle. In addition the original data is synchronized with the low pass filtered data for mixing in the next stage. The number of logic cells to perform the real time two-dimensional low pass filter is 2432 (XC4028).

The mixer chip performs high frequency boost by multiplying the original image by a factor H and subtracting the low pass filtered image multiplied times a factor K. To maintain the DC level of the image H – K = 1. However it proved very useful to maintain the independence of the relationship for debugging the PCI board. The mixer design utilizes a 40 MHz 12 bit multiplier with subtractor to implement $H\,?x_{Original} - K\,?x_{LPF}$. Cropping is performed at the output by controlling the writes to the field buffers. The number of logic cells to perform real time mixing is 770 (XC4008).

6. Conclusion

Since the final product will use the combination of boost and kernel adjustments, it is very crucial to understand and test the combined effects. Based on the simulation study, the following recommendations are made:

1. The boost rate β should be at least 50% for appreciable image enhancement. It is therefore possible to let the user to adjust its value from 50% to 100%.
2. The low pass filter adjustment σ between 3 to 7 for kernel size of 15, results in having 20 kernels which can be changed by downloading the Xilinx.
3. The Xilinx designs can be modified with the offering of newer larger and faster parts now available. If the system specification were increased to 1Kx1K 30 frames/s it can be achieved with increase clock rate of 33/66 MHz. Additionally the low pass filter and mixer can be combined in a second generation into one XC4062 FPGA. More importantly these FPGA designs illustrate the capabilities of present FPGA technology to perform image processing tasks which require a high degree of accuracy such as medical imaging.

References

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