P-11: Spatial Noise and Non-Uniformities in Medical LCD Displays: Solution and Performance Results

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Abstract: *This work describes a method to characterize the spatial noise and non-uniformities present in high-resolution medical displays and a technique to solve the problem. We designed a medical display with built-in compensation for the spatial noise at pixel-level and we are able to demonstrate improved image quality.*

Keywords: LCD, noise, uniformity, pixel, compensate, mammography

1. Introduction

More and more LCD replaces traditional CRT displays for medical imaging. LCD technology has improved a lot in the past years and has important advantages over CRT. However there are still some aspects of LCD that raise questions on the usefulness of liquid crystal displays for very subtle clinical diagnosis. One drawback of modern LCD displays is the existence of spatial noise [3] expressed as measurable stationary differences in the behavior of individual pixels. This type of noise can be described as a random stationary image superposed on top of the medical image being displayed. It is obvious that this noise image can make subtle structures invisible or add non-existent patterns to the medical image [1, 2]. In the first case, subtle abnormalities in the medical image could remain undetected while in the second case it could result into a false positive.

2. Method

A 5 Mega Pixel monochrome LCD-panel with 1024 levels of gray is used for our research. For the characterization of the spatial noise we use a digital high-resolution cooled CCD-camera with very good linearity.

The calibration of the camera is extremely important for achieving an accurate noise map. We calibrate the camera with a flat field and a dark field image. The dark field is used to compensate for the response of the camera when no light is present and is generated by taking a camera image in a dark environment. This self-response of the camera is caused by the creation of electron-hole pairs in the CCD even in absence of incoming light. The dark image depends on the integration time and the temperature of the CCD; this dark image is subtracted from the future acquired images. The flat field is used to equalize the response of the CCD-pixels of the camera. This is achieved by taking an image of a very uniform light source (integrating sphere). This image is then normalized and inverted and the result is multiplied with all future camera images after dark-field correction.

In a first step we characterize the spatial noise present in the display by measuring the luminance value of each display pixel by means of the camera. This is achieved by displaying a specific video level over the complete area of the LCD display and taking detailed images of all display pixels. For each display pixel an according luminance value is obtained from the images resulting in a map of 2560x2048 luminance values. The spatial noise map for that video level is then obtained by subtracting the mean luminance value from the luminance map. We used 14-bit quantization of the camera luminance values to guarantee sufficient precision of the noise map. When comparing the spatial noise patterns for several video levels we noticed significant variations and therefore the characterization process was repeated for multiple video levels.

A second step comprises of calculating appropriate correction values for each of the display pixels and this for all video levels. These correction values are eventually added to the actual pixel data and are selected so that all display pixels show the same luminance value when driven with the same video level. The final output luminance of all pixels after correction is equal to the mean luminance value over all display pixels before correction. In that way there is no drift in mean output luminance because of the correction applied. The correction is performed on a pixel-by-pixel basis so there is no spreading of noise to neighboring pixels and the full-resolution of the display is retained. After calculation of the correction values the precorrected images are displayed on the LCD and the accuracy of the correction is verified with the CCD-camera.

Figure 1 shows an example of the correction process: pixel data is precorrected before being sent to the LCD panel. If no uniformity correction were used then the overall result perceived by the user would approximately look like the precompensated pixel data shown in figure 1.

Specialized hardware in the display (called PPU or Per Pixel Uniformity) performs real-time and user-transparent reduction of the LCD spatial noise based on the calculated correction map. Each pixel value that is sent to the LCD-panel is first precorrected as described above in order to obtain a uniform output and to remove the spatial noise between the individual LCD-pixels. The correction algorithm is implemented in a gate array because of the large computational requirements and fast processing requirements. Also note that the correction values need to have a 10-bit precision in order to have a sufficient improvement of image quality. Using lower precision correction values can even reduce the image quality: 8 bit correction values introduced contouring and other visual artifacts in the final image.

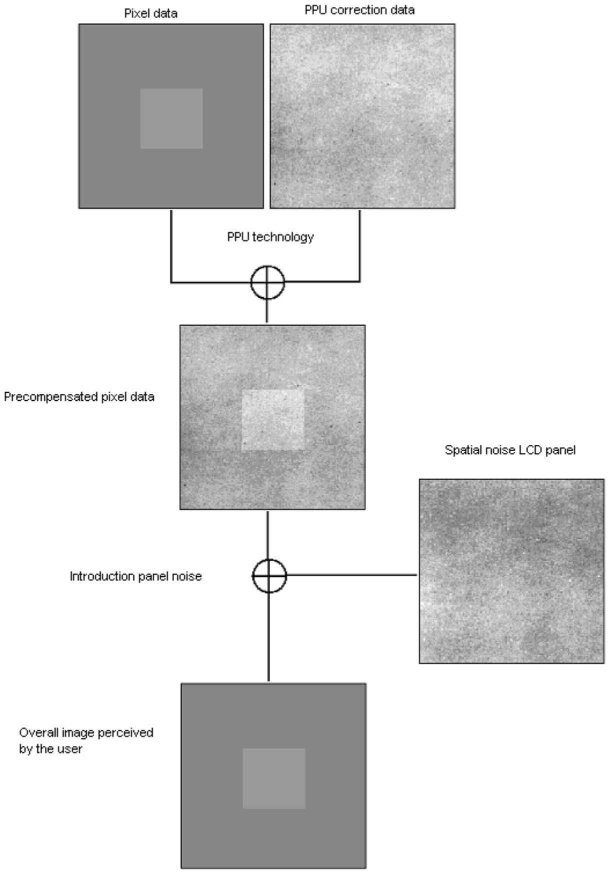


Figure 1. Correction principle

To measure the effect of our noise-compensation objectively we used several image quality metrics. A first metric is the RMS-noise before and after compensation: RMS noise expresses how strong the average noise is compared to the image signal. Another metric we used is luminance uniformity. The luminance uniformity is calculated as L_dark divided by L_bright, where L_bright is the luminance of the brightest part of the area and L_dark is the luminance of the darkest part of the area. In datasheets of medical LCD panels one usually distincts between luminance uniformity of adjacent areas (uniformity within a circular area of 10mm placed anywhere on the screen) and screen total luminance uniformity (uniformity over the entire screen area). Finally we also examined the NPS or noise power spectrum of the display. The noise power spectrum is obtained by applying a Fourier transform to the map of pixel luminance values. The NPS is very important because it clearly indicates how strong the image noise is at different frequencies and this both for horizontal and vertical directions. The NPS was measured for the LCD display with and without the uniformity correction.

3. Results

We first analyze the nature of LCD spatial noise. Figure 2 shows two detailed areas of each 256x256 display pixels of a non-compensated LCD. In absence of LCD noise these images would show a uniform white picture. The images clearly show that the LCD noise has two distinct components: there is the typical gaussian noise and on the other hand there is a non-gaussian noise component present. This non-gaussian noise, also called systematic noise, introduces phantom artifacts that can take various shapes: circles, ellipses, lines, crosses … The systematic noise component is the most dangerous component: the human eye is highly trained to detect systematic (noise) patterns and because the systematic noise can take any shape it can be easily confused with real signal patterns present in the medical images.

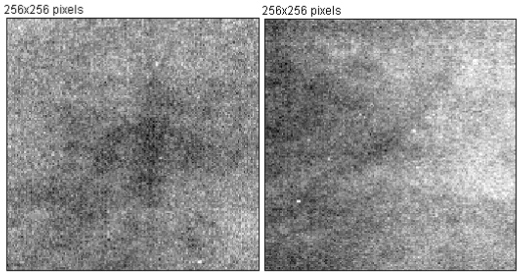


Figure 2. Detailed picture of 256x256 pixels

Especially in mammography radiologists look at small image features and also use the shape of objects to base their diagnosis on. It is therefore easy to understand hat the systematic noise patterns of the LCD can reduce reliability of medical diagnosis [4].

We now evaluate the performance of the Per Pixel Uniformity technology. A first performance metric is luminance uniformity for the complete area of the display. Figure 3 shows the results for video levels 32 (3.125% DDL), 128 (12.5% DDL) and 1000 (97.66% DDL). The left hand side shows the uniformity without PPU and the right hand side with PPU. The plots clearly show that the spatial noise patterns severely depend on the video level. That is why it is necessary to use different correction data for different video levels. Without correction the overall luminance uniformity is typically around 70% while after correction this is increased to over 95% and this for all video levels. Note that the European Standard for Digital Mammography requires a luminance uniformity of at least 90% [5].

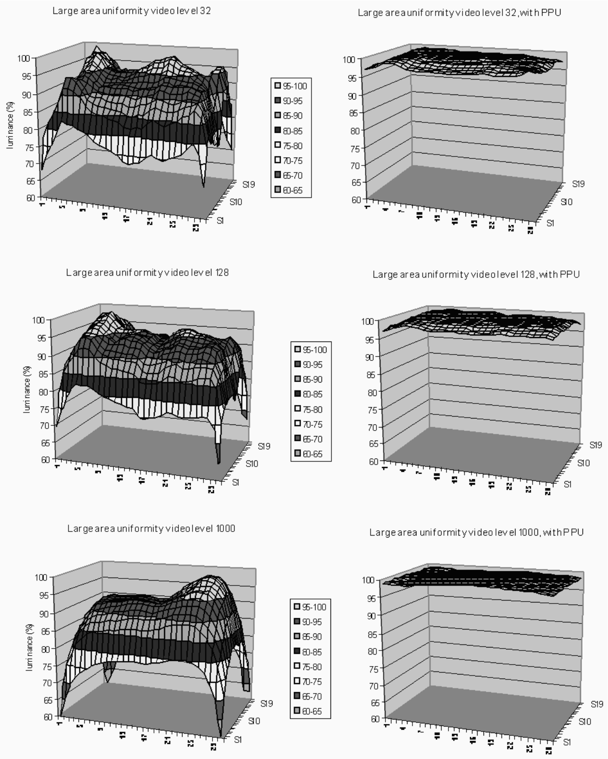


Figure 3. Uniformity before and after correction

Figure 3 only shows global non-uniformities whereas we indicated that especially the high-frequency non-uniformities (systematic noise) are important. Therefore we also analyzed a detailed area of 256x256 pixels before and after the uniformity correction. Figure 4 clearly shows that before the correction systematic noise is present: the lower part is darker and the upper right side shows a bright stain. After correction on the other hand, there is only pure gaussian noise visible: all systematic noise and phantom structures have been removed.

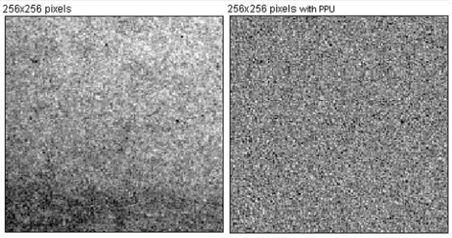
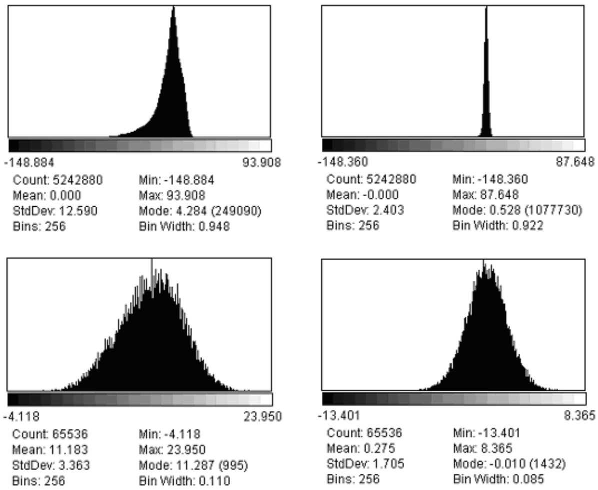


Figure 4. 256x256 pixel area without and with PPU

The reason why there is still noise present after correction is the noise floor level of the measurement equipment. As with any measurement device there is a small noise signal present in the images taken by our cooled CCD camera. This results in a small remaining noise pattern in the compensated LCD but because the remaining noise is purely gaussian it is much less a problem for medical displays.

A second performance metric is the RMS noise. Figure 5 shows a statistical analysis of the LCD luminance output per pixel and this for the complete display area (top) and a 256x256 pixel area (bottom). The left hand side shows results for the uncompensated display and the right hand side for the same LCD with PPU. The metric used in figure 5 is “video levels”.

The complete uncompensated display has a minimum value of –149 meaning that the darkest point of the display was 149 video levels below the mean luminance of the display. At the same time the brightest point was 93 video levels above the mean luminance value resulting in a peak-to-peak noise of 242 video levels. The standard deviation for the complete display area was 12.6 video levels for the uncompensated LCD and this was decreased to 2.4 video levels by enabling the PPU technology. Also looking at the histogram makes clear that the non-uniformity has been significantly reduced. It is interesting to see that for the uncompensated LCD even the small 256x256 pixel area (appx. 4x4 cm²) has peak-to-peak noise of over 28 video levels and the standard deviation is about 3.4 video levels.



```
-148.884                              93.908
  Count: 5242880       Min: -148.884
  Mean: 0.000          Max: 93.908
  StdDev: 12.590       Mode: 4.284 (249090)
  Bins: 256            Bin Width: 0.948
```

```
-148.360                              87.648
  Count: 5242880       Min: -148.360
  Mean: -0.000         Max: 87.648
  StdDev: 2.403        Mode: 0.528 (1077730)
  Bins: 256            Bin Width: 0.922
```

```
-4.118                                23.950
  Count: 65536         Min: -4.118
  Mean: 11.183         Max: 23.950
  StdDev: 3.363        Mode: 11.287 (995)
  Bins: 256            Bin Width: 0.110
```

```
-13.401                                8.365
  Count: 65536         Min: -13.401
  Mean: 0.275          Max: 8.365
  StdDev: 1.705        Mode: -0.010 (1432)
  Bins: 256            Bin Width: 0.085
```

Figure 5. Statistical noise analysis

The results presented in figure 5 also indicate that it has no use to increase the number of gray scales in modern LCD displays without at the same time performing noise reduction at pixel level [2]. Indeed, if the number of gray scales is increased (for instance from 1024 to 2048) then the difference between the gray scales becomes smaller and therefore the relative strength of the LCD noise increases accordingly.

Figure 5 contains information about the magnitude of the noise patterns. Another very important aspect is the frequency behavior of the LCD noise. The NPS (noise power spectrum) is shown in figure 6 and represents the noise strength at several spatial frequencies going up to 0.25 times the pixel frequency (noise patterns of 4 pixels in size or 0.66 x 0.66 mm^2). A distinction is made between horizontal and vertical direction and the NPS was measured both with PPU disabled and enabled. The NPS was calculated by performing a Fourier transform on the spatial noise images.

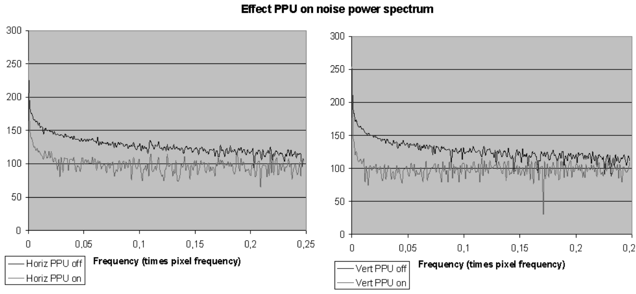


Figure 6. NPS without and with PPU

Both the vertical and horizontal NPS show a significant decrease in noise by activating the PPU technology and this for the complete frequency range. The stronger noise at lower frequencies can be explained by the strong luminance fall-off near the borders of the uncompensated display. An important conclusion is that the PPU technology is also able to reduce the very high frequency noise. In particular this high-frequency noise can easily interfere with small image features that are important for instance in mammography.

4. Conclusions

We presented a method to characterize the spatial noise and non-uniformities present in high-resolution medical displays and a technique to solve the problem. A medical display with built-in compensation for the spatial noise at pixel-level was developed and we were able to demonstrate improved image quality. Especially for very subtle clinical diagnosis such as mammography the described methods could be an important step forward because the noise-compensation completely removes all systematic noise patterns from the display and therefore reduces the risk of false positives and increases the probability of detection of subtle true structures in the image.

5. Acknowledgments

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6. References

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