

# SIGNAL PROCESSING APPLICATIONS FOR INFORMATION EXTRACTION FROM THE RADIATION OF VDUs

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## KEYWORDS

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## ABSTRACT

*In this paper, the idea of reconstruction of the content of a screen on an external computer monitor has been presented and different enhancement techniques for the serial data and reconstructed image have been evaluated. One of the important part of these studies is the time-domain analysis of emanation data in a totally computer controlled environment.*

## INTRODUCTION

Increasing speed of digital equipment moves the electromagnetic compatibility (EMC) studies into a new point due to their broadband radiated emission characteristics [Craw92]. Beside the protection of equipment and humans from the electromagnetic radiation, it is desired to prevent the interception and analysis of classified information from the radiated and/or conducted emissions.

One of the interesting sources of information is the video display units (VDUs) or computer monitors. Especially, radiated emissions from the computers' VDUs can reach very high frequencies. The video signal bandwidth can be high as 10 or 20 MHz. Moreover, for periodic signals, the probability of detection increases. If the structure of the signal is also known, correlation and averaging techniques can be used for further analysis.

The starting point of the studies about the eavesdropping risk of the VDUs was a research program carried out by the Dr. Neher Laboratories of the Netherlands PTT [EckV85], [EckV91]. They picked up information displayed on a remote video screen placed in a building from large distances with a very high frequency (VHF) band III antenna, a receiver system, and a television screen.

All of these studies proved that information displayed on a computer monitor can be easily reconstructed from the radiated emissions. However the time-domain data also contains all the screen map data such that considering the scanning method each character can be recognized in a computer [Hill91]. The basic idea behind that is to capture one frame at a time in the computer and monitoring the frame and line pulses. After having synchronized with the source screen, one can analyze the pattern of 1's and 0's, each corresponding to a pixel value.

In this work, the information captured from the radiated and conducted emissions from the computers' VDU is analyzed and recognized.

The display content of the tested personal computer was reconstructed on an external monitor. Finally, reconstruction was done by processing serial data on a computer.

The main problem with the reconstruction is the noise that corrupts the data in different ways: additive, convolutive or both. Therefore, the effect of noise should be reduced as much as possible. To handle with the noise, several techniques including adaptive filtering and image processing were used and the results are evaluated.

When measurements are done inside an anechoic chamber that is free from environmental noise, the reconstructed image is almost the same as the original screen. In this study, a GTEM Cell was used to record radiation data that is processed.

All instruments were fully automated and software controlled via an IEEE-488 standard bus. The reconstruction program is simply a raster the previously recorded or real-time emanation data by selecting appropriate synchronization rate, sampling frequency and range. Software was written in LabWindows/CVI<sup>®</sup>. For a good coverage, a high-speed data acquisition card was used.

## COMPUTER VIDEO SYSTEM

The analysis of electromagnetic interference (EMI) or EMC characteristics of digital computers can be very complicated since there are a lot of parameters that affect these emanations. The sources of the emanations can be the monitor or computer chassis (hard disk, keyboard, mouse, etc.). Monitors are the dominant source of interference and they can be analog or digital. Also the resolution types, synchronization rates, and operating modes determine the spectral profile of the computer.

The VDU screen is consists of pixels and these pixels are arranged in horizontal line. Electron beams from cathode ray tube (CRT) scan these lines. Each character is built up from M×N matrix. It is called as a character cell. According to the electron beam in the CRT (on - off modulated) some of the pixels will be highlighted (white spot) while some of them not [Koks98]. In color monitors, three components, red-green-blue, construct the video information. In graphics mode (e.g. Windows<sup>®</sup> 3.x, 9x), a monitor can display any bit-mapped image. In graphics mode, variety of shapes and fonts can be displayed. In text mode (e.g. MS-DOS<sup>®</sup>), all of the color components are in same voltage level while their intensities vary in graphics mode. Hence, the level of emanations is directly related with the color pattern of the screen contents.

One of the important parameters in measurements is horizontal scan rate. Horizontal scan rate is a measure of how many scanlines of pixel data the monitor can display in one second. It is controlled by the horizontal sync signal that is generated by the video card, but is limited by the

monitor. Vertical scan rate measures the maximum number of frames that can be displayed on the monitor per second at a given resolution. It is controlled by the vertical sync signal coming from the video card. Multisynchronous monitors capable of syncing to video signals within a range of frequencies.

## MEASUREMENTS AND RESULTS

### Frequency Domain Measurements

Observing frequency-domain characteristics, i.e. radiated emission properties, of the environment and the effect of the PC is very useful to get an idea about the tuning frequency that will be used in the time-domain measurements [Will96]. By comparing the ambient level and the emissions from the PC, an initial estimate can be done about the frequencies at which these emissions are dominant.

All emission measurements were done in CDC to get rid of the undesired environmental effects. The results were recorded graphically with the ambient level and all measurements were fully automated. The effects of different resolutions, color schemes, fonts, and character patterns on spectral characteristics were observed [Koks98].

### Reconstruction of Display Contents: Hardware

A current probe or a broadband antenna was used to pick up emissions. Another computer monitor was used as an external monitor to view the reconstructed picture.

The radiated emissions collected by the transducer were fed into the super heterodyne receiver. Detected emissions were demodulated and amplified. This demodulated time data was given to the external monitor's video input. To obtain the picture, vertical and horizontal synchronization signals were supplied from two signal generators. If these synchronization frequencies are not adjusted correctly, the video screen will scroll up and down or the information will be distorted.

The receiver must be tuned to a suitable frequency with a wide bandwidth to obtain best image quality on the external monitor. At this point, the results obtained from the first part were used as a reference. The frequencies where the

highest emission levels occurred were chosen. Also, the receiver's bandwidth must be at least 10 MHz since video signal bandwidth is very high. Lower resolutions blurred the image, caused distortions, and hence decrease the signal to noise ratio.

Reconstruction test setup is a sort of digital signal/image processing system [Jain89], [Koks98]. The building blocks are given in Figure 1. The video signal samples obtained from the receivers' z-axis output were also stored on a personal computer for analysis part.

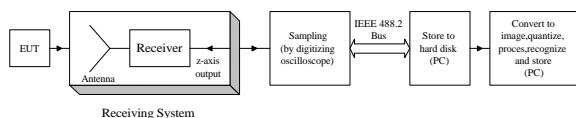


Figure 1. Blocks of Reconstruction Test Setup.

## Reconstruction and Enhancement of Display Contents: Software

Although, the display contents of a remote computer can be reconstructed on an external one from a couple of meters, the understanding of this captured data is not an easy job. The information is hidden inside the emission data which also contains environmental noise, emissions from the other electronic devices and internal noise. Using several devices such as filters, lock-in amplifiers, etc. can enhance this noisy data received from the antenna. Also software based enhancement tools can be applied to this data. Emission data can be stored in a serial format or can be converted to the still picture.

For this purpose, a small rastering program was developed which retrieves raw data, and reconstructs the screen shot according to the line sync rate entered interactively by the user. To store complete frame data at the same time, a high-speed data acquisition system is needed with approximately 1 MB memory module on it. In other words, 640x480 resolution with 60 Hz refresh rate means that  $640 \times 480 \times 60 = 18.43$  MB information in a second.

For data recorded in low noise, the synchronization signals were clearly distinguishable and one can easily reconstruct the image using this synchronization information. But, for noisy data, the synchronization information is lost and an estimate has to be made about where to start

reconstruction. To handle with this problem, a software have been developed which interactively permits an operator to adjust the starting point of the reconstruction to catch the synchronization.

To illustrate the idea, a reconstructed image is given in Figure 2. The serial video data was recorded in the GTEM Cell, and a Word<sup>®</sup> document was open. Since the effect of noise is rather small, the reconstructed image is very close to the original screen.

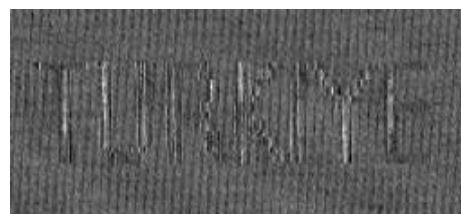


Figure 2. Reconstructed Word<sup>®</sup> screen

Figure 3.a shows another reconstructed image from the clean data. Again, the computer was in the GTEM Cell and the analog data was sampled at 50 MHz. Figure 3.b is a reconstructed image from noisy data. The data was recorded at the laboratory and it is difficult to identify the characters.



a. Reconstructed "TURKIYE" from clean data (background was white and the text was black)



b. Reconstructed "TURKIYE" from noisy data (background was white and the text was black)

Figure 3. Comparison of Environments

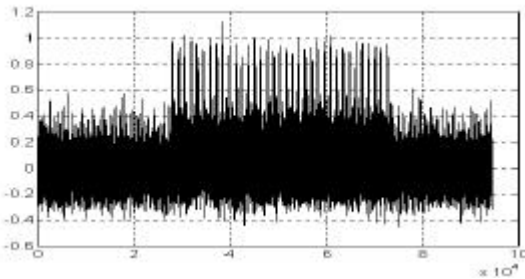
Another problem concerning reconstruction was the assignment of colors to the different

(voltage) values of the data. For gray scaled images, white color was assigned to the maximum-valued sample and black color was assigned to the minimum-valued color. For data values between them, gray scaling was done via linear interpolation.

In Figure 4.a an image reconstructed using this technique is given. The data was taken by an antenna placed 3 m away from the computer and receiver parameters were set to appropriate values so as to get the best serial video data which was being radiated from the computer. Although the data shown in Figure 4.b, is rather noisy, the reconstructed image is surprisingly clear. This is due to the fact that the text color was set to light-gray which produces the most powerful radiation, and the background color was set to blue which produces rather small radiation out of the computer. The effect of noise, therefore, can easily be removed by a threshold assignment.



a. Reconstructed “TEMPEST” from noisy data (the background was blue and the text color was light-gray)



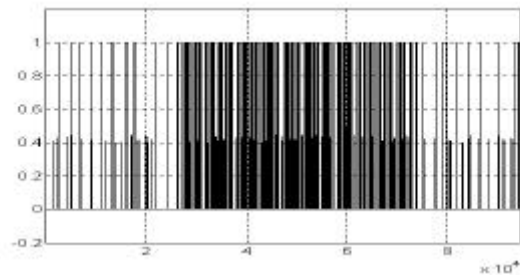
b. Noisy serial video data for “TEMPEST”

Figure 4. Color effect

### Enhancement of Reconstructed Image by Thresholding

In order to obtain more clear images, obviously, one should use some enhancement techniques for the serial video data. Some image processing techniques were used to enhance the reconstructed image but it was understood that these image processing techniques work only when the serial data are in a suitable form. So the first step in obtaining clear images is to enhance serial video data using appropriate techniques. One intuitive

approach is to employ threshold levels. The data values that are higher than a certain threshold were assigned white and the data values that are less than a certain threshold were assigned black. Again the data values between two threshold level were assigned different gray levels obtained by linear interpolation. For this serial data, 0.45 was chosen for white level and 0.4 for black level. The resulting serial video data and corresponding image is given in Figure 5.a and Figure 5.b, respectively. It is worth to say that these thresholds were determined by the operator according to the clearance of the reconstructed image. The image reconstructed after thresholding was significantly improved and the effect of background noise, except some spurious white pixels, was almost completely removed by this technique. But unfortunately, as it will be seen later, for some data whose text and background levels are close to each other, thresholding can not do much improvement.



a. Thresholded serial video data



b. The image obtained after thresholding

Figure 5. Thresholding serial data

### Averaging of Different Frames

Another approach to reduce the noise is to average the data that are recorded for different frames. This is a very useful method to get rid of noise for periodic signals. The content of the screen is the same for all frame data. But, the noise components of the frame data are essentially uncorrelated. Thus averaging of different frame data should reduce the noise while strengthening the screen component.

Using a data acquisition card, we were able to record two subsequent frame data at a time. Thus continuing with this fashion, many frame data can be recorded. However in averaging, alignment of the different frame data creates a problem. Different frame data have to be aligned so that the averaging procedure works. When the alignment is done wrongly, the resulting frame data get worse.

The alignment algorithm that is used can be summarized as follows; First of all, a part of data is chosen to be the frame data. If the data is proved to be a good candidate for the frame, then, that part of the data is searched in the remaining recorded data. The frame is slid by one sample at each step and the correlation coefficient is calculated between the candidate frame and the overlapping part of the searched data. When two frames overlap, the correlation coefficient takes on its maximum value. Thus the starting point of another frame is determined. Afterwards, starting from this point, the data of equal length of the candidate frame are picked and assigned as another frame.

Calculation of the correlation coefficient is not a difficult but somehow time-spending procedure. Once the two data are determined, the correlation coefficient can be calculated as follows; first, the means and variances of the two data are determined. This has to be done in a practical sense rather than in a statistical sense. Therefore, sample mean should be used as an estimate of the mean and sample variance should be used as an estimate of the variance. The definitions of sample mean and sample variance are given in (1.1) and (1.2), respectively.

$$m_x = \frac{1}{N} \sum_{n=1}^N X[n] \quad (1.1)$$

$$\text{var}\{X\} = \frac{1}{N} \sum_{n=1}^N \{X^2[n] - m_x^2\} \quad (1.2)$$

where N denotes the number of data samples. Then using these estimates the covariance of two data can be calculated.

$$C_{XY}[n] = \frac{1}{N} \sum_{n=1}^N (X[n] - m_x)(Y[n] - m_y) \quad (1.3)$$

Lastly, correlation coefficient can be found using (1.4).

$$r[n] = \frac{C_{XY}[n]}{\text{var}\{x\} \cdot \text{var}\{y\}} \quad (1.4)$$

An example of frame alignment is given in Figure 6. Figure 6.a is the frame to be searched and Figure 6.b is the serial video data containing two frames. In Figure 6.c, the computed variation of the correlation coefficient is shown. According to this variation, the first frame starts from the sample at which correlation coefficient takes on its first maximum value. Similarly, the starting point of the second frame can also be identified.

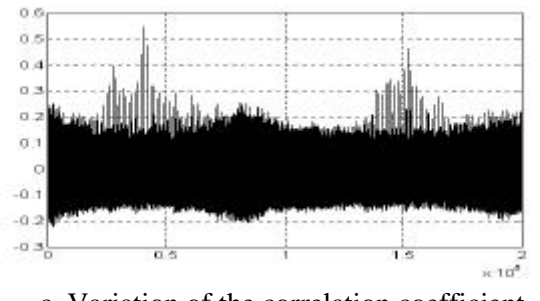
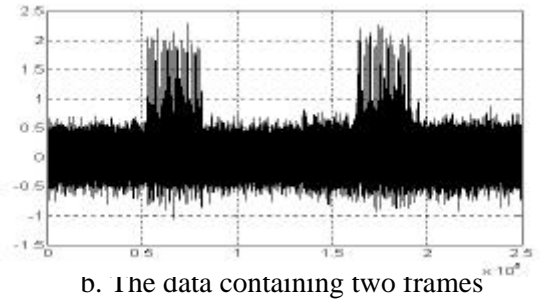
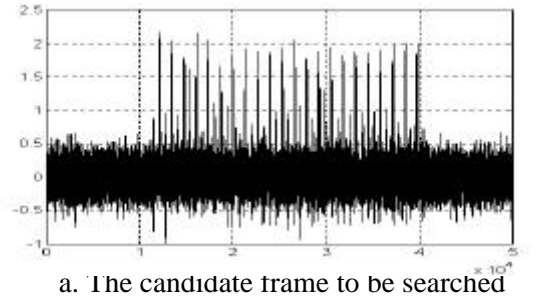


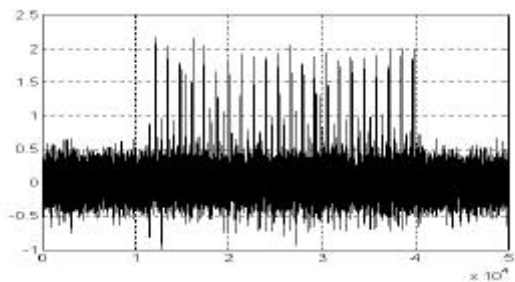
Figure 6. Frame averaging

To illustrate the improvement of averaging, consider the images in Figure 7 and Figure 8. In Figure 7.a and 7.b, an unprocessed serial video data and the reconstructed image from the data are given, respectively. Figure 8.a and 8.b are the serial video data obtained from averaging 13 frame data and the reconstructed image from the data is given. The ability of averaging to reduce the noise is obvious. Naturally, the serial data having high SNR resulted in a clearer image.

As seen from the Figure 7 and Figure 8, background noise is considerably removed by averaging. Sometimes, such large number of frame (e.g. 13) may not be available, then more efficient techniques have to be used to enhance the video data.

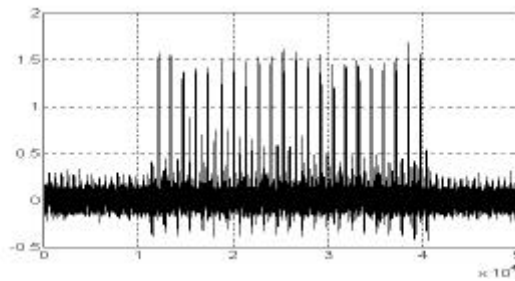


a. An unprocessed serial video data



b. The image reconstructed from the data (a).

Figure 7. Unprocessed data and reconstructed Image



a. The serial video data obtained from averaging of 13 frames



b. Reconstructed image from the data (a)

Figure 8. Averaged frames and reconstructed image

### Multichannel Signal Enhancement

Noise reduction techniques when more than one data (or channel) are available are proposed. One efficient technique is multichannel adaptive

filtering for signal enhancement. The technique was essentially proposed for additive noise, not for convolutive noise; therefore it is a partly solution to this problem [Yapa99b].

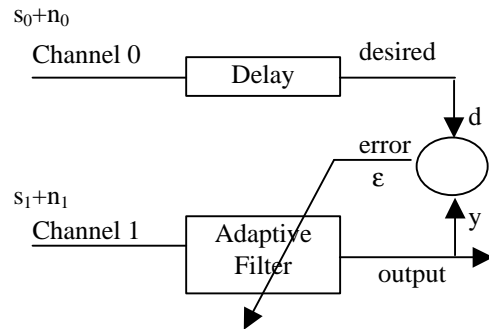


Figure 9. Two channel signal enhancer

In Figure 9, the two-channel signal enhancer is given, its working principle is as follows; the zeroth input contains signal  $s_0$  and the noise  $n_0$ , the other channel contains signal  $s_1$  and noise  $n_1$ . The signals  $s_0$  and  $s_1$  are correlated in some way, but, they do not need to be of the same waveform. The noises  $n_0$  and  $n_1$  are essentially uncorrelated with both each other and the two signal components. The adaptive filter, iteratively, adjusts its tap-weights via any suitable algorithm. Most commonly used algorithms of adaptation are *Least-Mean Squares* and *Recursive Least Squares* and variations of the two algorithm [Hayk96]. After convergence, the error power  $\epsilon$ , which is defined as the difference between the filter output  $y$  and the desired response  $d$ , is minimized. The filter output is then a *best least squared estimate* of  $d = s_0 + n_0$ . Since  $n_0$  is uncorrelated with the input  $x = s_1 + n_1$ , the filter output turns out to be a *minimum mean-squared error estimate of  $s_0$  alone*. A delay, equal to the half of the order of the adaptive filter, is included in the desired response to achieve the performance that would be obtained if the adaptive filter could be noncausal [Ferr81], [Yapa99a].

Similarly, in multichannel case, each input is adaptively filtered by different filters and then all filter outputs are summed to produce an output which is subtracted from the desired response to get the error signal. The weights of the adaptive filters are simultaneously adjusted via any suitable algorithm in accordance with the error. Thus, the output, after convergence, is a best least square estimate of the signal component that exists in each channel [Ferr81].

In Figure 10, the reconstructed image from the output of the four-channel signal enhancer is given. It is very close to that obtained from averaging. But in this case, just 4 aligned frame data, rather than 13, were used to make the enhancement. The number of tap-weights of the filters was chosen on the order of 6. In the reconstructed image, a low-pass effect was introduced by the adaptive filtering. Therefore, the *number of* tap-weights was intentionally kept small to minimize this disturbing effect.



Figure 10. Reconstructed image from the output of the four channel signal enhancer

### Comparison of Different Enhancement Techniques

In Figure 11.a and b, a reconstructed “TUBITAK-UEKAE” image from noisy data and its thresholded counterpart is given, respectively. Thresholding improves the image somehow but it also introduces some wrongly-placed white pixels.



a. Reconstructed noisy image



b. Thresholded image of (a)

Figure 11. Thresholding Serial Data

In Figure 12.a, the image reconstructed from averaging data is given. In averaging 13 different frame data were used. Enhancement of averaging on the image is clearly visible. The image given in Figure 12.b, is the thresholded counterpart of (a).

The same threshold levels were used in reconstruction. As seen, almost no wrongly-placed white pixels are in the thresholded image.



a. Reconstructed image from averaged data



b. Thresholded image of (a)

Figure 12. Thresholding Averaged Data

In Figure 13.a, the image obtained from multichannel enhanced data is given. The enhancer had four channels. The four channel signal enhancer successfully removes the effect of background noise. But, the low-pass effect of the enhancer is clearly visible in the thresholded image, given Figure 13.b. Again, the same threshold levels were used in reconstruction.



a. Reconstructed image after filtering.



b. Thresholded image of (a)

Figure 13. Filtered Data

As a result, when the available frame data are large enough, averaging can be used. But, if there are not enough data for averaging, then, multichannel signal enhancer (with two or more

channel) can efficiently be used according to available number of frames.

## Enhancement and Recognition of Reconstructed Image

The emission data stored in the reconstruction part was analyzed and converted to two-dimensional picture. Then, images were binarized, and suitable spatial filters (if desired) were applied. After this pre-processing, they were dilated, and the possible objects were labeled with different colors. Several features were extracted from the original character set [Koks98].

## CONCLUSIONS

In this paper, the idea of reconstruction of the screen content on an external computer has been presented and different enhancement techniques for the serial data and reconstructed image have been evaluated.

It was observed that, several parameters affect the spectral contents and properties of the VDUs. It carries information about the operating mode, relation between character formats, etc. [Koks98].

The first intuitive solution to the reconstruction problem was to set threshold. This technique works well when the radiation level of the two color forming the screen are distinct enough. Otherwise, thresholding procedure leads to spurious white pixels and corrupts the image.

Second technique was averaging. This technique is indeed rather useful when many frame data are available. Experiments has showed that when thresholding is used after averaging, it provides a high degree of improvement on the reconstructed image.

Lastly, a multichannel adaptive filtering for signal enhancement has been proposed. The performance of this technique is very close to that of averaging but the advantage is that it does not require many frames. In this study, four channel signal enhancer was used and satisfactory results were obtained.

The feasibility of using the image processing algorithms for detailed analysis and character recognition was examined. Original recorded serial data did not give the desired results. It is

concluded that before detailed image processing applications, serial data has to be enhanced.

As a by-product of this study, a complete software package has been developed in LabWindows/CVI<sup>®</sup> which is a rather appropriate language for laboratory studies. It has the ability of reconstructing images from serial video data, aligning and picking frame data for signal improvement and enhancing the video signal via both averaging and multichannel adaptive filtering. The work concerning to optimize the software is still in progress. Also, converting gray-scale images to original color image by statistical analysis is another part of our studies.

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