A GENERAL TELEPROOFING SYSTEM

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ABSTRACT

Manual preparation and transport of the proofs from the repro house to the client is currently a costly and time-consuming task. To avoid this problem most CEPS-manufacturers offer teleproofing options to their systems. However, the teleproofing systems on the market are limited to the equipment of a certain CEPS-manufacturer. The system constructed in the VTT's Graphic Arts Laboratory is more general, because it digitizes the analog monitor image of an arbitrary CEPS preserving all lines. The image is transferred through the public 64 Kbit/s ISDN network to the workstation of the client. Because the digitizer is adaptive, the system can be interfaced to all significant CEPS. The prototype is based upon standard personal AT-compatible computers equipped with telecommunication cards under the X.21 protocol. Using 6-fold compression; a 1023-line colour monitor image is transmitted in 50 seconds. The communication protocol developed allows transmission without an error. The paper describes the main features of the system.

1. INTRODUCTION

Even though the individual phases of the pagination process are largely computerized, communication *between* the phases is still to a great extent physical. Page design, text and image production and printing are linked together mainly by physical media - paper and film. This slows down pagemaking and makes it less flexible.

The pagemaking process is by no means an information stream that travels only forwards. It contains plenty of iterations. The repro house or department may send several proofs of the same page to the customer, before the work is accepted. It takes time, raw materials and money to prepare and transport these proofs. To produce an

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analog proof, the separations have to be output on films, the films have to be combined into a paper proof, and the proof transported to the customer. [Sch,90] gives an example of a typical package printing work that contains 5 proof iterations and takes one week to implement.

2. TELEPROOFING

Teleproofing or remote proofing means that the proof is made at a different geographical location than the CEPS (Colour Electronic Prepress System). The digital information needed for the proof is transmitted through the telecommunication network. The proof can be output on the monitor and/or on a physical medium.

Teleproofing considerably saves time and money, because the repro or printing house does not have to prepare physical intermediate proofs and have them transported to their clients. It also provides a closer link between design and implementation.

Some CEPS manufacturers offer teleproofing options. Some of these solutions are broadband telecommunication links between the manufacturer´s CEPS units, like SciNet/Link from Scitex [Sch,90]. This means that the client - for example an advertisement agency - must invest in a relatively expensive CEPS unit to obtain the teleproofing capacity. In addition, the CEPS options can be used only with certain CEPS equipment and are thus not general.

3. A GENERAL TELEPROOFING SYSTEM

The teleproofing system developed by VTT transmits colour images, as displayed on the monitor of the CEPS, via the public digital data network to the monitor of the receiver in the design bureau [Söd,91a]. This monitor-to-monitor transfer enables the designer to follow how the repro house implements his/her page design. The designer may check the details of the received image by zooming.

The system does *not* aim at solving the very difficult problem of correspondence between the original, the monitor image, the proof, and the printed picture [Söd,91b]. The goal is much more modest; to offer the designer and the repro worker a common visual reference in the form of a monitor image. As the image is transmitted in less than a minute, the operator gets rapid responses to his work. Monitor screen transmission is straightforward and low-cost compared with the transmission of full resolution images. On the other hand, a monitor proof is normally not good enough to be a basis for the final acceptance. A traditional physical proof is therefore needed and the task of the teleproofing system is to eliminate the intermediate proofs.

3.1 Design principles

A number of technical design principles were expressed at the beginning of the development project.

3.1.1 Generality

The system has to transmit pictures from all major CEPS systems. This is the hardest design problem to solve, because the digital image is represented in different and device-specific ways in the CEPS. It is almost impossible to retrieve the image in a digital on-line form from a wide range of CEPS. Present standardization efforts on ANSI and ISO for digital proofing (IT8.4) will make the new CEPS more open which will only gradually affect the installed base of repro systems.

Therefore, our approach is to apply the common denominator of all image processing systems: the image monitor. By digitizing the analog RGB signals of the CEPS monitor, we get access to all CEPS. The difficulty is, of course, that the frame grabber must adapt to the variations in the monitor signals - bandwidth, line number and refresh format (interlace/non-interlace).

An additional requirement is that all the horizontal lines of the monitor images have to be grabbed. As we failed to find the frame grabber on the market that would meet these requirements of adaptivity and full line resolution, we decided to design one (*see chapter 4*).

3.1.2 Low-cost with standard platform and public network

The experiences gained with earlier teleproofing systems show that the solution must be low cost to be accepted by the design and repro houses. Therefore we chose to base our system on low-cost standard hardware - MS-DOS and IBM AT compatible computers equipped with add-on cards. Similarly, we chose to use the 64 Kbit/s public digital data network to keep the transmission costs down. This network also means generality: the coverage of the one-channel pre-ISDN network is almost 100 % in Finland and in 1993 on also the three-channel ISDN network will have total coverage in Finland.

3.1.3 Shorter transmission time with compression

To maintain a reasonable pace in the image communication, the transmission must take place in not more than one minute. As the amount of digitized data is in the range of 1.5 to 3 MB, a simple computation shows the need for image compression. A fast algorithm was developed for this purpose (*see chapter 5*).

3.1.4 Invisibility fo the CEPS user

Teleproofing must not disturb work at the CEPS. Therefore, the monitor signals have to be digitized in real time. This makes the teleproofing system almost invisible to the CEPS user.

3.2 Overall operation

The working principle of VTT's system is as follows (*see fig. 1*). The adaptive frame grabber in the sending PC digitizes the RGB signals of the CEPS monitor. The digital image is compressed by a factor of six and transmitted without an error through the switched public data network (64 Kbit/s) to the receiver PC. The image is decompressed and shown on the monitor and/or stored in the disc memory. In addition to disc storing, the received image may be zoomed, sized and annotated. Naturally, the received picture can be routed to other workstations through the LAN. Images can be received unattended, e.g. by night, and be stored on disc for later viewing.

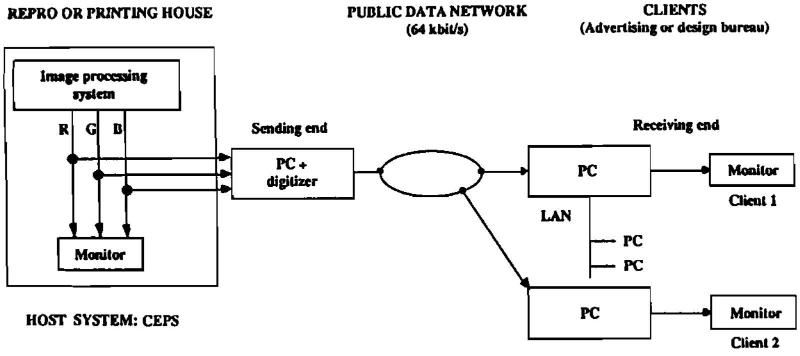

Figure 1. The working principle of the VTT's Teleproofing System.

3.3 Hardware configuration:

In addition to the PC and the frame grabber, the sender consists of a telecommunication add-on card under the X.21 protocol and an ISDN network terminal. The receiver PC includes the telecommunication card and an image processing card, which controls the auxiliary high-resolution colour monitor (*fig. 2*).

Figure 2. The receiving station of the teleproofing system.

4. THE ADAPTIVE DIGITIZER

4.1 Reasons for designing a new type of frame grabber

The teleproofing system digitizes the high-quality monitor images from CEPS. So the monitor signal digitizing process is exceptionally demanding. The viewers are professionals and appreciate quality. If the quality is lost in digitizing it cannot be returned artificially.

The frame grabber market was scanned to find a suitable product but none was found. There are many PC compatible grabbers which digitize conventional NTSC or PAL signals. However, they were not suitable for this application. There are many reasons for that and we shall take a closer look at them.

A new type of grabber was needed. The main requirements were:

- a very high digitizing frequency
- accurate synchronization due to text and drawings often included in the monitor screens
- flexibility.

4.2 The weak points of conventional frame grabbers

It is ironic that a $100 B/W TV can handle video signals that are too difficult for a $10000 image grabber. The grabber designer has always to struggle against space problems. He/she must place almost same features in an essentially smaller space than a TV designer does. In most cases, the grabbing feature is of a secondary importance compared to the displaying of the image. These limitations are clearly visible in the hardware solutions.

High-quality image processing systems generate pixels at the speed of 30 MHz or more. Shifting from one pixel to another is a violent process. The spectrum of signals goes far up to high frequencies due to the discrete nature of pixels. However, it is reasonable to assume that in digitizing images the maximum signal frequency is half of the pixel frequency. For example, if a system generates pixels at the speed of 30 MHz, the maximum sine wave approximation drawn by this system is 15 MHz and even then one period of the sine wave is composed of only two pixels. It is also reasonable to demand that at least one sample is taken from every pixel despite the fact that sampling and generating frequencies are not equal. This agrees (more or less) with the Nyqvist criterion.

Beside, the human eye forgives many features which would be intolerable in technical measurements. Most frame grabbers have digitizing frequencies of 10 to 14 MHz. Sometimes a multiple of NTSC or PAL subcarrier frequency of up to near 18 MHz is used. It is clear that these frequencies are far from sufficient for monitor signals. If you use such a grabber the image will be undersampled. There are alias components, lack of contrast, etc.

If you have a 512 line grabber and work with 1023-line monitor images you do not get all the lines. The image is undersampled also in the vertical direction whrer undersampling takes an even more severe form. High-quality CEPS images contain 1023 lines, sometimes about 800 lines but practically never less than that. With a 512 line grabber the whole image area is grabbed in the horizontal direction although undersampled. In the vertical direction the bottom part of the image is simply left out. If a NTSC grabber is used to grab a 1023-line image, about 500 lines are lost with no trace at all of what was in the image.

Some frame grabbers can handle images of up to 800 lines or more. The images are undersampled but readable. We tested one such product and noted that it shared the common problem of inaccurate synchronization. The synchronization process has two problems: 1) adapting to the line frequency of the incoming video signal, and 2) detecting the start of the line.

A typical frame grabber synchronization solution consists of a phase-locked pixel oscillator. The frequency and the phase of the oscillator is adjusted so that exactly the required number of pixels is taken from each line. The length of the line may vary a little with no effect on the number. Even if some line synchronization pulses are omitted, no lines are lost. This is the strength and the weakness of the line-locked oscillator. The oscillator takes 500-1000 pixels for each line synchronization pulse and at a frequency that is 500-1000 times higher than the line frequency. The pixel oscillator must operate for a relatively long period without information of the correct phase. If the line synchronization pulses are somehow irregular (as they often are in image processing systems especially at the start of the frame) the frequency drifts away from ideal value and is partly corrected after the next proper synchronization pulse. This partial correction is often oscillatory by nature. The pixel frequency oscillates around the ideal frequency causing distortion in the image geometry. In some cases a straight vertical bar takes the form of a sinusoidal bar.

The phase lock is a narrow band oscillator. It is a good solution with strictly standardized and highly regular video signals are used but not when flexibility and precise geometry is required. The phase lock is a natural solution for CRT devices. They have a delicate vacuum tube that is prone to burning if the scanning is stopped. The yokes have a high resonant energy and the phase cannot be changed for every sweep. A solid state PC board is without such limitations.

Interlacing or non-interlacing is another synchronization problem. Low line frequency monitor signals are almost always interlaced and the highest frequency ones almost always non-interlaced. Systems using line frequencies of about 30 kHz may be either interlaced or non-interlaced. The interlace format of the monitor image is often a built-in part of the grabber hardware and difficult to adapt to other interlacing formats.

4.3 New solutions

When we started designing the new grabber, it turned out that the grabber would contain a large memory (3,5 MB) with associated digital circuitry. Designing such things is not very innovating or interesting. However, this approach was finally chosen. We shall also present here another, completely different solution which may be of technical interest. We call it a "one-line- grabber". It was not fully designed or built yet, only a short system design was made. The primary goals were extremely high image quality and the lowest possible cost.

4.3.1 One-line grabber

The images on the screen of image processing systems are often static. For example, an advertisement is created or a photograph is processed for a journal. This means that images can be grabbed taking only one line from each frame using slow scanning. The fast image memory may be small and the large image memory could be a PC disk. Grabbing the whole image is a slow process although grabbing one line may take place at a very high sampling frequency. With this technique it is possible to produce a very high quality and a very cheap grabber (for example 4,000 pixels/line at 100 MHz). The price is paid in the form of a long grabbing time.

4.3.2 New high quality frame grabber

The new high quality grabber was developed in three steps: 1) theoretical analysis, 2) constructing and testing of a prototype as a component of the teleproofing system, and finally: 3) applications of the experiences to build a commercial production version.

The requirements set for the grabber:

- real time true colour grabbing
- digitization with 8 bits/colour
- sampling frequency of 10-50 MHz
- a flexible number of pixels/line up to 1024 pixels/line
- a flexible number of lines/frame up to 1024 lines
- flexible line frequency of up to 65 kHz
- flexible field frequency of up to 120 Hz
- flexible interlacing format
- geometrical distortion less than 1/2 pixels
- programmable black and white levels.

The displaying of the image was not important and was left out to have much more space for the digitizing circuitry.

Compared with conventional solutions, the main theoretical difference is the synchronization circuitry. The traditional phase locked concept was discarded. It is hard to create a phase locked oscillator to meet the above specifications and therefore another approach was chosen.

The phase lock was replaced by a phase-synchronizable relaxation- type voltage controlled oscillator. The oscillator is controlled by software. The sampling frequency is locked to a standard frequency without comparing the phase. The phase of the oscillator is synchronized individually at the start of every line without affecting the oscillating frequency. This gives very good geometrical properties far better than 1/2 pixels. It may sound surprising, but this solution is simpler than the conventional approach. However, there is a price to be paid for the above benefits. A missing synchronization pulse means that you lose the whole line. This rarely happens and in image processing systems never in the active image area. In most cases a missing line is a better choice than a distorted or shifted line. Adapting to changes in the line frequency is slow compared with that of the phase lock.

The interlace problem is solved by software. A processor on the board checks the interlace format of the image and unpacks the format to a conventional non-interlaced format. There is no fixed format in the hardware. The processor can handle virtually any interlace format.

Some theoretical aspects had to be considered as well to make the grabber fast. Digitizing frequencies seem to have a technological limit at about 30 MHz. A/D converters beyond that limit are rare, expensive and hard to use. Also, the easy-to-use memories have typical access times of 35 ns. Pushing the frequency to 50 MHz or above means some new thinking.

It is possible to use multiple slow A/D converters to digitize a fast signal, if one can control the sampling phase and aperture of each converter. This also allows the use of slower memories. We first experimented with fast converters and multiplexing the digitized pixels to slower memories. This results in very strict timing. The final solution consists of two converters working with the phase shift of 180 degrees with specified and controlled sample and aperture times. It is possible to have TTL-compatible kHz and relatively cheap memories.

4.4 Theoretical limitations of the new solutions

The new features of the high-quality grabber are the relaxation principle in synchronization instead of the phase lock approach and the phased A/D conversion. They have many practical advantages compared with other solutions. We must, however, take into account theoretical limitations.

The main limitations are:

- noise (colour error)
- changes in digitizing frequency or phase (geometrical error)
- differences in the two-phased A/D converters (symmetry error)
- non-zero sampling window (aperture error)
- violation of the Nyqvist criterion (alias component error).

Random noise is generally not a problem in monitor signal processing due to the high signal levels. The main sources of noise in PC applications are the power supply noise and the irregularities in A/D converter linearity. PC chopper power supplies are noisy and the chopper frequency tend to be visible to human eye due to its regular properties if injected into images. It is essential to have filtering on the board. This noise component was of the order of 1-8 grey levels in our first prototype. The prototype was built with two-layer board technology for research purposes and no attention was paid to the noise. The final version has not yet been tested. It is a four layer board and has filtering for analog voltages. A big improvement in the value is to be expected.

The relaxation oscillator principle is noise tolerant but not immune to noise. At the maximum speed one pixel means only 20-30 ns. An accuracy of 1/2 pixels means 10-15 ns repeatability. Repeatability is the key word here. The absolute timing of the synchronization pulses is not important if their repeatability during one frame is good. The oscillator frequency is voltage controlled and thus prone to noise. The wideband pixel oscillator consists of several marrow band oscillators grouped together. So the reaction of the selected oscillator to the control voltage noise is reduced to a low level.

In practice the two A/D converters have a phase different from the ideal 180 degrees. This reduces the theoretical Nyqvist bandwidth of the system. The phase error is caused by skew in electronics and differences in the A/D converters. In practice, no degradation in the image quality with reasonable phase errors. These phase differences are not specified for fast A/D converter but they may be assumed to be at most 2 ns. The skew of electronics and the printed circuit board is less than that. The phase error can be tens of degrees (worst case value) causing some loss of horizontal resolution. Pixel oscillator frequency has noise. This noise means that sampling intervals are not exactly constant but have interval jitter. This is, however, of no serious concern.

The A/D converter itself determines the sampling aperture. Also the aperture time has jitter. A non-zero aperture means non- linear filtering of the signal. An aperture jitter of 100 ps at a signal frequency of 25 MHz means degradation of the theoretical accuracy from 256 levels to 64 levels. The internal jitter of fast A/D converters is rarely specified but it is normally less than 100 ps. The jitter is in fact the limiting signal level accuracy factor and the higher the signal frequency the worse the jitter problem gets. In low frequency digitization, the jitter is not a problem.

4.5 Grabber control

The software can be divided into three groups: diagnostics, downloader, and frame grabbing. Software was written both in TMS 34010 assembler and the C-language. The former naturally runs on the grabber board and the latter in PC. Diagnostics was used mainly in the hardware development. The frame grabbing software had not been placed into ROM, so a downloader was needed to read the TMS -program code into the grabber memory. After downloading, the PC/AT host communicates with the grabber via the common memory area of the grabber. Both the host and the grabber poll this postbox. After grabbing, the host reads the image from the memory of the grabber, compresses, if needed, and dumps the data into a file for transmission.

5. COMPRESSION

An image transmission system can be either on-line or off-line. In an on-line system transmission time is composed of file transfer, compression and decompression. The teleproofing system works on-line. There is a simple equation for the channel bandwidth, the compression bandwidth and the highest achievable speed-up for an on-line still-image transmission system:

speed-up = channel bandwidth / compression bandwidth

Compression bandwidth means here the throughput rate of the compression/decompression procedure (Kbytes/s). For example, if we have the system, which has channel bandwidth of 250 Kbytes/s (= 2 Mbits/s) and the compression scheme can compress data at 500 Kbytes/s, the highest possible speed-up is two. This is the highest compression ratio that is meaningful to use.

The teleproofing system uses a 64 Kbit/s channel. JPEG/ADCT was first chosen for the compression algorithm. Unfortunately the software we developed was too slow, so a block truncation coding - BTC - algorithm was eventually used in the system. The BTC -algorithm was implemented in its basic monochromatic form [Del,79]. The method divides an image into 4x4 pixel blocks, each of the pixels is individually quantized into two levels, while the block sample mean and variance are preserved. If eight bits are used for both the mean and the variance, the compression ratio is 4.

With colour images the compression ratio is 6, because RGB images were first transformed into a colour space which was a modification of 4:2:2 YUV colour space (4:2:2 means that every other chrominance pixel is omitted). A modification of the 4:2:2 algorithm was needed to decrease the amount of floating point operations. The BTC algorithm needs some square root operations. These and some other operations have been calculated in advance into look-up tables to speed up the compression. The compression software has very few floating point operations and does not need a math co-processor.

6. TELECOMMUNICATION LEVELS

The telecommunications of the teleproofing system can be divided into 5 hierarchical levels:

Physical level: This level consists of the telecommunication card, the data network terminal and the public digital network. The control of the network terminal takes place through the telecommunication card. This is a serial port which works faster than the normal RS-232 port and obeys the X.21 telecommunication protocol.

Device control: This program level controls the telecommunication card and indirectly the network terminal according to the X.21 protocol. At the upper levels it offers services like connect/disconnect, dialling a number, send/receive a data block, and HDLC checking of the correctness of the transmitted data block.

Block transfer protocol: This level uses the services of the previous level to transmit a block of data and check if the block has arrived without transmission errors. The protocol allows that the block transfer is repeated until it is transmitted correctly. This protocol gives a transmission without any error.

File transfer: Two types of files are transmitted: image files and supervisory files. The image files are in the TARGA-format and supervisory files contain non-imagery data like the file names. The files are divided into blocks, that contain for example 1 KB of data.

Communication control: The communication control keeps track of the transmission. It initiates the commands, dials the phone number, automatically generates file names, checks timeouts. The sender is the active part, and the receiver the passive part.

7. EXPERIMENTS

The pilot system was tested at a major repro house - Reprostudio Luomanen & Raunio - in Helsinki. It was interfaced to a Chromacom 2000 system from Hell. The transmission of all the 1023 lines of the monitor image to our laboratory in Espoo took 50 seconds with compression and 5 minutes without compression. The quality of the received image was assessed by a group of repro experts and was found to be good and very close to that of the CEPS.

The system has also been hooked to other CEPS´s and DTP-systems with line frequencies varying between 15 kHz and 63 kHz. The image quality has been found to be good in all the cases.

8. CONCLUSIONS AND FURTHER DEVELOPMENT

A general teleproofing system has been built for rapid communication between the page designer and the CEPS operator. It is general, since it transmits images from any CEPS. This is possible by digitizing and transmitting the analog control signals of the CEPS monitor. A good image quality is achieved by applying a new method of synchronization in the frame grabber. The monitor image at the receiver is judged to be of nearly equal quality as the CEPS monitor image. Compression makes transmission time under one minute to enable flexible communication between the designer and the CEPS operator.

An evident improvement in the system would be to include the retransmission of the annotated image to the sender. This can be done by current hardware if an image processing card and monitor are included in the sender. Another evident improvement is to take full advantage of the ISDN connection by using two channels to double the transmission speed.

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