Section II. Systems and program

A low-cost system for digital image processing of moving images in real time: application to X-ray fluoroscopy

Lorenzo P. Gómez 1, Julian Mejuto 1 and Juan J. Vidal 2

1 Departamento de Electrónica, Facultad de Física, and 2 Departamento de Radiología, Facultad de Medicina and Hospital General de Galicia, Universidad de Santiago de Compostela, Santiago de Compostela, Spain

A low-cost image processing system and two real-time digital image processing algorithms using parallel processing have been developed to provide automatic equalization of moving images at video frequencies. The algorithms differ in the processing time required and the characteristics of the final image. The system takes an entire image from the video sequence, digitizes it, automatically calculates its histogram and the lowest and highest useful grey levels, equalizes the histogram, and finally converts it to the analogue image. Methods were applied to X-ray fluoroscopy (angiography) images, which are usually saturated or of uniform intensity (low contrast), leading to information loss. An application of these methods is in interventional radiography, which requires images in real time.

Real-time moving image processing; Fluoroscopy; Image enhancement; Interventional radiography

1. Introduction

It is well known that real-time digital processing of moving images, as a consequence of the large amount of information to be processed and the speed of calculation required, generally needs special processors. Nevertheless, there are situations when the type of operation performed on the image data arrays is not excessively complicated, although the improvement of the image quality can be quite great; pixel-to-pixel operations, for contrast improvement or pseudocoloring, being just such a case [e.g. 1, 5]. If the tasks the image processor must perform are optimized, it is possible to implement them in low-cost systems.

In X-ray fluoroscopy (Fig. 1), the range of attenuation of the patient's anatomy is frequently greater than the range of signal values that can be reproduced by the intensifier and the video camera of the fluoroscopic system combined. Although modern fluoroscopy systems have ways of overcoming the problem, this imbalance gives uniformly intense (low contrast) or saturated images, leading to information loss. The problem is especially important in the case of interventional radiography, for which the images have to be in real time and be of the highest possible quality [e.g. 2, 7]. The work discussed here shows how real-time digital image processing techniques have been used to improve such images.

2. Description of the system

The system used (Fig. 1) employs an image processor (frame grabber) with A/D and D/A convertors capable of digitizing moving images at
video frequencies [3], connected in parallel to the fluoroscopy system.

The general scheme (Fig. 2) may be divided into two blocks: the frame grabber, including an image processor, and a computer (host computer) which usually controls the former or works separately. However, it is possible to program the processing system as is described in section 4, so that the frame grabber and the host computer operate in parallel.

A Data Translation DT2651 frame grabber and DT2656 auxiliary frame processor from Data Translation Inc. were used (Fig. 3), the latter was only necessary for the second algorithm. The DT2651 has one input and one output look-up table, the latter being charged with image equalization. Connection to the host computer, a Microvax II, was via a Q-bus. An almost identical system with a similar frame grabber (DT2862) connected to the bus of a PC-AT is being tested. The precision of the processor is in both cases 512 \times 512 pixels of 8 bits. The system was programmed using the subroutines libraries of the frame grabber: the DT-IDL from Data Translation for the Microvax II and the DT-IRIS from Data Translation for the PC-AT.

To test and develop the system, we used two S-VHS video recorders [6] and monitors, connected to the input/output of the digital image processing system (Fig. 2). The tapes used as input were recorded directly from the fluoroscopy system. Point-to-point operations, such as modifying the contrast of an image and pseudocoloring, are performed using the look-up tables.

3. Proposed method of equalization

The problem indicated previously was solved by employing two algorithms that automatically provide a real-time (video frequency) contrast improvement of moving images by equalizing the
histogram of the input images, whose range of grey levels is not usually adapted to the total range \((0, 255)\), as follows:

Let LEAST be the lowest useful grey level in the original image and MOST the highest useful grey level (Fig. 4) where: LEAST = first grey level
Let $Y_0$ be any grey level of the original image and $Y_e$ that of the expanded image, then

$$
Y_e = \begin{cases} 
0 & \text{if } Y_0 < \text{LEAST} \\
255 \frac{Y_0}{(\text{MOST} - \text{LEAST})} & \text{if } \text{LEAST} \leq Y_0 < \text{MOST} \\
255 & \text{if } Y_0 > \text{MOST}
\end{cases}
$$

In our system, exponential and logarithmic transforms have also been used instead of the linear transform. LEAST and MOST are the experimental values giving maximum contrast enhancement in our fluoroscopy system, but they can be obtained using different criteria or algorithms, depending on the characteristics of the system used.

**4. Processing algorithms and times**

To implement the processes described, it is necessary to calculate the histogram of the image, the values of LEAST and MOST and the look-up tables, in that order. For this, two algorithms have been developed: in Fortran for the first system (Microvax II) and in C for the second (PC-AT), using the subroutines library of the frame grabber, where this is either DT-IDL or DT-IRIS.

Flow-charts for these algorithms are shown in Fig. 5a and b. It is necessary to distinguish between the two loops: the conversion loop and the calculation loop. The loops operate in parallel, but have different processing times, the calculation loop being much slower than the conversion loop. They overlap each other while taking the image stored in the frame grabber memory to calculate the histogram, and during the programming of the look-up table. The result of the first loop is the equalized image and that of the second loop are the values for programming the look-up tables.

In the first algorithm, the conversion loop, shown in Fig. 5a as a continuous line, consists of the acquisition of an image frame, A/D conversion, storage in the frame grabber memory, transformation of the grey levels using the look-up table and D/A conversion of the frame, the loop closing with the A/D conversion of the next frame of the image sequence. This loop is carried out at video frequency.

The calculation loop, shown in Fig. 5a as a broken line, includes the transfer of the image stored in the frame grabber memory to the host computer RAM, calculation of the image histogram and the values LEAST and MOST and programming of the look-up table as described in section 3. This frees the frame grabber from having to perform these operations, allowing it to carry out the conversion loop at video frequency. Programming the look-up table using this method takes about 1 second, which is longer than the time the conversion loop takes to be executed.

In the second algorithm, Fig. 5b, the system needs to be fitted with a DT2658 auxiliary frame processor (Fig. 3b), which is charged with calculating the histogram of the image stored in the frame grabber memory. Significant savings in calculation time are thus made. The histogram is transferred to the host computer for calculation of the values of LEAST and MOST and programming of the look-up table. The conversion loop comprises the transformation of the grey levels of the image stored in the memory and its D/A conversion, since the configuration and control of the DT2651 frame grabber and DT2658 auxiliary frame processor have two consequences: firstly,
while the auxiliary frame processor calculates the histogram, the image stored in the frame grabber memory cannot change; secondly, storage in this memory of the image digitized by the A/D converter has to be delayed until this calculation is complete. When these conditions are fulfilled, the frame grabber memory is loaded with the image for which A/D conversion was being or was about to be carried out, closing the loop.

D/A conversion is performed on the image stored in the frame grabber memory. The flow-chart corresponding to the second algorithm, shown in Fig. 5b, is very similar to that of Fig. 5a with the exception that the process of storage in the frame grabber memory is interrupted for the time corresponding to execution of the calculation loop.

Although the second algorithm offers a higher histogram calculation rate and a correspondingly

![Flow-chart](image-url)

Fig. 5. (a) Flow-chart corresponding to the first algorithm. (b) Flow-chart corresponding to the second algorithm.
Fig. 6. Low contrast image of a sequence and its histogram.

Fig. 7. Image corresponding to Fig. 6 after processing.
high rate for programming the look-up table (for each new output image), the output frame rate is less than video frequency, corresponding to the time of calculation, which is about 8 separate images per second, depending on the histogram calculation time.

For the first algorithm described, images are output at video frequency, this being greater than the programming rate of the look-up table, which takes about 1 second to execute. Therefore sudden changes in contrast of the moving image, such as changes of scene, which lead to large changes in the histogram of that frame, while not often occurring in sequences of fluoroscopy images, take this time to be corrected.

5. Results

Angiograph frame images of the same sequence before and after processing, on which the corresponding histograms have been superimposed, are shown in Figs. 6 and 7. There is a large improvement in contrast around the subclavian vein and the spinal column.

This system has also been tested on saturated and low contrast conventional moving images taken in the laboratory with a video camera. Illumination of the subject was carried out using a light source which was alternately turned on and off. Considerable improvements in contrast were achieved.

6. Availability

The programs for the two algorithms had very few lines. These programs and full information on this subject (in Spanish) are contained in ref. 4 which can be obtained on request from the first author of this paper.

References