Multiple image control with an 8-bit frame grabber. Use in a Vander Lugt correlator

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Introduction

The reduction of geometrical distances in optical correlators, in order to build miniaturized systems, has become a necessity for realistic applications [1]. In general, the scope of the studies carried out is only focused in some parts of the problem. Nowadays, liquid crystal devices (LCD), usually removed from commercial videoprojectors, are used to display images in optical setups. As a result of using pixelated panels, the viability study of building an optical correlator in a reduced space should not be only limited to a design of optical systems. It must include an analysis of the behaviour of the displaying devices. Another issue that has not been raised yet is the reduction of the material needed to control simultaneously two LCDs in a Vander Lugt correlator, which involves a duplication in the driving electronics.
We analyze in depth several engineering problems regarding the construction of a Vander Lugt correlator with LCDs at the input and Fourier planes. In order to reduce the length of the setup we have designed two telephoto systems. An original method to control both devices with a single 8-bit frame grabber and a single videoprojector electronics is presented. We have solved the problems related to pixel-by-pixel control when displaying the data from the frame grabber on the LCDs. An accurate analysis of the phase modulation capability of the panels is also discussed. Experimental results obtained with this setup are presented.

Liquid crystal devices characterization

The LCDs used in this work have been removed from an Epson VP-100PS videoprojector. However, the electronics of the videoprojector still drives the images displayed on the LCDs. Kirsch et al. [2] studied the characteristics of a similar piece of equipment, an Epson Crystal Image Videoprojector E1020, but we have found some substantial differences.
Each videoprojector has three LCDs, one for each RGB channel. In the correlator we use only two of them. The active area of these LCDs is 25.6x19.8 mm, which corresponds to 320x264 pixels. The size of the pixels is 55x50 μm and the center-to-center distance is 80 μm, horizontally, and 75 μm, vertically. Figure 1 shows a schematic drawing of its characteristics. As shown, a small fraction of the active area is not used by the electronics to display images (see details in a next section).

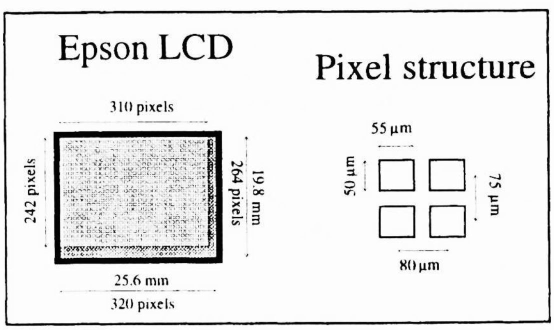

Figure 1: Schematic drawing of the LCD structure

The frame grabber used in the experiments is a Matrox PIP-1024B with an RGB output. This digitizer board stores an image of 512x512 pixels with 256 grey levels (8 bits per pixel).

Operating curves of the LCDs

The operating curves of the LCDs give information on the way in which these devices modulate light depending on the grey level assigned to each pixel. The light can be modulated in amplitude, in phase or in both simultaneously. This complex transmittance depends on the polarization state of light and on the addressing voltage applied to each pixel. When placing an LCD between two polarizers, different configurations of the device, that give rise to the different operating curves, depend on the position of the polarizers as well as on the potentiometer control positions (bright, contrast and color) of the videoprojector. When a single videoprojector is used to address two LCDs the aforementioned controls have to be set in a compromise position and the final operating curve adjustement has to be carried out by rotating the polarizers. The choice of the operating

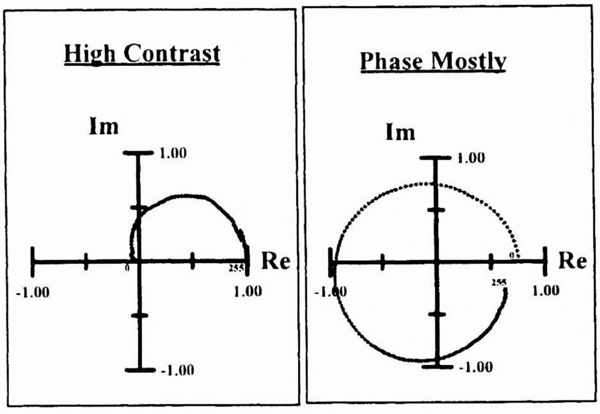

Figure 2: Operating curves of the LCDs

curves for each LCD has to be taken into account in order to optimize the results in the correlator [3]. The most common configurations used to display images on the LCDs are: High Contrast (HC), Amplitude Mostly (AM) and Phase Mostly (PM).
The characterization of the LCDs is divided into two parts. The amplitude modulation is obtained directly measuring the transmited light and the phase variation is determinated by an interferometric-based method as explained in Reference [4]. For the LCD used to display the scene we have found an operating curve corresponding to a HC configuration while a PM configuration curve has been obtained for the second LCD (see Figure 2). These two curves have been found with a single position of the videoprojector potentiometer controls.

Addressing of the LCDs

In order to deal simultaneously with two LCDs, usually two control systems are needed to manage the signal. We present an original method to control both modulators with a single electronic system. The LCDs are driven by the electronics of a videoprojector and a single frame grabber is used to send the images, scene and filter, to the devices. With this method we reduce the equipment involved in the correlator because only one displaying system is required, obviously gaining in simplicity and economy. We also present a pixel-by-pixel addressing method in order to have a correct display of the images on the LCDs.

Storage of two images in a single 8-bit frame grabber

The frame grabber we use stores an 8-bit image of 512x512 pixels. To deal with two images each byte (8 bits) has to be shared by the pixels of both images. In our method, the most significant nibble (4 bits) is occupied by the scene and the less significant nibble is used by the filter. Therefore, the number of grey levels of each image has to be reduced from 256 to 16 to be codified into a nibble. This is equivalent to stripping off the less significant nibble of the pixels of each image. Then the grey level stored in the frame grabber is generated by joining the two resulting nibbles into a single bite. Figure 3 summarizes the procedure.
Since the digitizer has an RGB output it is possible to create different look-up-tables (LUT) for each channel. By using two appropriate LUTs, the two images information stored in a single byte can be separated in two different channels. Figure 4 shows the LUTs designed for the green and the red channels, respectively. As it can be seen in the figure, only the most significant nibble of the new generated byte is relevant for the green channel while the output of the red channel only depends on the less significant nibble. The RGB output of the frame grabber is connected to the RGB input of the videoprojector. Note that the blue channel is not used. The use of a single videoprojector presents an additional advantage with respect to driving the LCDs with two independent electronics, because in the latter case an accurate adjustment of the synchronism signal is needed.

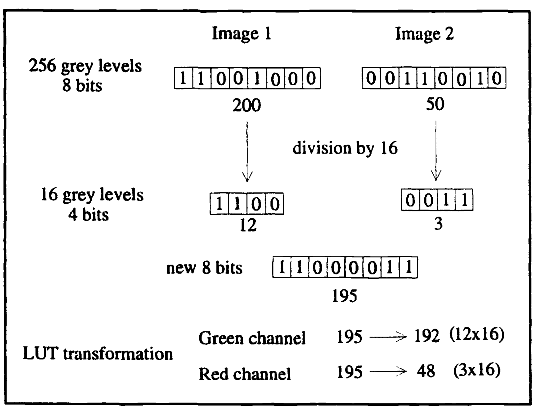

Figure 3: Method to control two images in the frame grabber

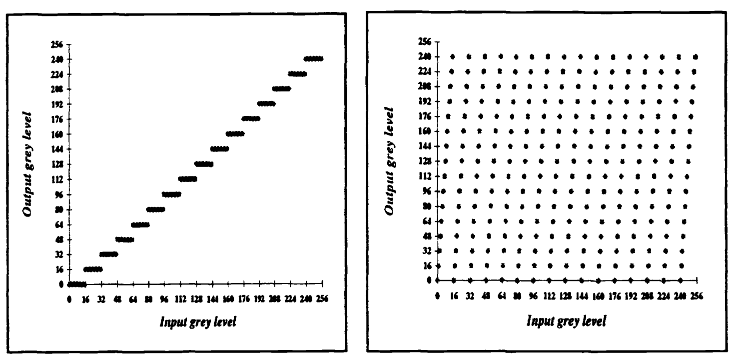

Figure 4: LUTs for the green and the red channels, respectively

The main advantage of this method is to reduce the equipment involved in the setup though there are a few disadvantages. The two images should be the same size and should be stored in the same memory position of the frame grabber. The potentiometer controls of the electronics have to be fixed in the same position for all the possible configurations of both LCDs. Another disadvantage is the reduction of the number of grey levels of the images, though it is not significant in the correlation results. Finally, it has been seen that there is cross-talk between the two LCDs. Empirically it has been observed that, for a certain position of the color control, this phenomenon disappears almost completely.

Managing pixel-by-pixel addressing from the frame grabber to the LCDs

Although the nominal space bandwidth product of the devices is 320x264 pixels, we have found that only 310x242 can be used in our setup to display the images. On the other hand, the bandwidth of the digitized image in the frame grabber is 512x512 pixels. We have observed that the first 28 rows and 34 columns of the stored image are lost when addressing the LCDs with the frame grabber. Therefore, the real bandwidth of the digitized image is reduced to 478x484 pixels. The 484 rows are averaged two by two with an odd predominance, as it is shown in Figure 5, becoming the 242 active rows of the LCD. On the other hand, the 478 columns in the frame grabber become 310 interpolated columns. In practice, every third column is lost.

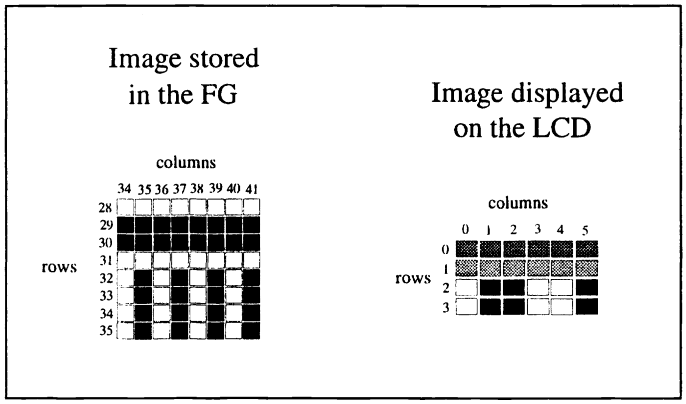

Figure 5: Image conversion from the frame grabber to the LCD

A procedure to maintain the pixel-by-pixel addressing of the images is presented. The images have to be sized to a maximum of 310x242 pixels. The rows are duplicated and a linear interpolated zoom is applied to the columns with a factor 1.542 (=478/310). With this method, the pixel-to-pixel control of images from the frame grabber to the LCDs is quite accurate, although the column addressing is more critical than the row one.

Distance matching

The optical setup used is a converging Vander Lugt correlator that is a modification of the classical 4f architecture [5]. The main problem that presents the 4f correlator is the need of large distances to work in the optical bench with the suitable elements and the appropriate scale. With the converging architecture the required distances are shorter than for the 4f system. There is another advantage in that it allows the modification of the scale of the Fourier transforms without changing neither the lenses nor the distances between them. This versatility simplifies the fitting between the optical transform and the filter.

To design the correlator, several considerations concerning the scales and distances involved in the optical setup should be taken into account. The scale factor (K) between the Fourier plane and the input plane can be calculated as $K=\lambda d$, where d is the distance between these two planes. This constant should be large enough to separate the diffraction orders generated by the pixelated structure of the first LCD. In general, the distance between orders has to be at least the size of the display [1]. Nevertheless, the required separation can be reduced to the size of the image, in this case 256x256 pixels. As we have pointed out before, the distance between pixels in the LCD is 80 μm horizontally and 75μm vertically. Using an input LCD with a non squared pixel grid produces a distorsion in the optical Fourier transform. Thus, the filter image has to be modified for a correct match. The simplest way to have a good fitting between filter and Fourier transform is to rotate 90° the second LCD.

Therefore, the minimum diffraction constant needed is $K=256x0.08x0.075=1.54$ mm^2, where the factor 256x0.08 mm is the size of the filter image on the second LCD and 0.075 mm is the pixel separation in the input LCD. From the minimum value of K required, the distance between the input and the Fourier planes has to be at least 2.436 m, with a He-Ne laser (λ = 633 nm) as illumination source. With a classical 4f correlator, this distance would be 4.87 m.

Although the total length of the setup is reduced with the converging correlator, is advisable the use of telephoto systems instead of single lenses. By using couples of converging and diverging lenses, tunable high value diffraction constants can be achieved in a minimum space [6].

Experimental results

A Vander Lugt optical setup with two LCDs in the input and Fourier plane controlled by means of a single 8-bit frame grabber and telephoto systems to perform diffraction has been designed and built. Figure 6 shows the three satellite scene used in the experiments. The target to detect is the smallest satellite, which is partially superimposed to the Earth. The original scene is 256x256 pixels and 8 bits per pixel (256 grey levels) . This image is reduced to a nibble per pixel and a zoom is applied to ensure pixel-by-pixel control as explained before. This modified scene is displayed on the first LCD working with a HC operating curve.

A phase-only filter (POF) of the target (the smallest satellite) has been used, taking into account the phase introduced in the scene by the HC configuration of the first LCD. The POF is computed from the complex values of the scene displayed on the LCD: let f(x,y) be the target and let $f^{\sim}(x,y)$ the complex valued function obtained after modifying f(x,y) with the operating curve of the LCD. Then, the POF is obtained in the usual way,

$$\mathrm{POF}(u,v)=\frac{\Im\{f^{\sim}(x,y)\}^{*}}{|\Im\{f^{\sim}(x,y)\}|}$$

Figure 7 shows the optical correlation between the scene and the POF matched to the smallest satellite. This result has been obtained with the second panel operating in the PM configuration.

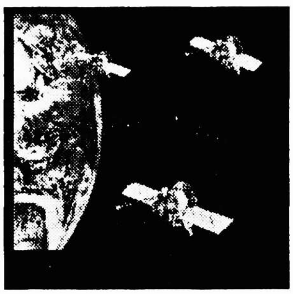

Figure 6: Satellites and Earth scene

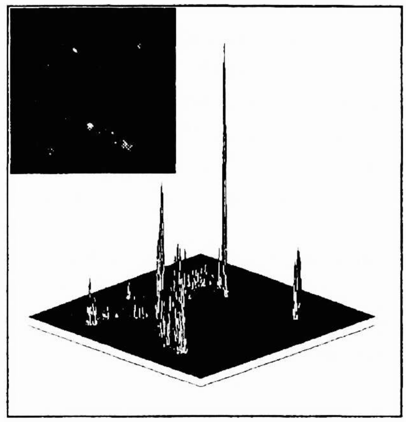

Figure 7: Experimental correlation

Conclusions

We have demostrated the possibility of simultaneously controlling two LCDs with a single 8-bit frame grabber and a single videoprojector electronics. The main advantage of the method proposed is the management of the correlator with the minimum equipment. Moreover, a complete study of the correlator involving: the use of telephoto systems to reduce the total length of the setup, a pseudo pixel-by-pixel addressing of the images from the frame grabber to the LCDs, and the analysis of the operating curves of the LCDs and their use in the design of the filters. The experimental optical results obtained show the good performance of the setup proposed.

Acknowledgments

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