

P-178: Modified Discrete Cosine Transform for Addressing Liquid Crystal Displays

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Abstract

An addressing technique that is based on modified discrete cosine transform (M-DCT) is proposed to drive RMS responding matrix displays. Time taken to switch from one arbitrary gray shade to another is almost independent of initial and final gray shades.

1. Objective and Background

Discrete Cosine Transform (DCT) is capable of achieving a high energy compaction ratio and it is extensively used in image compression. We have explored the possibility of using DCT to drive RMS responding matrix displays. There are several addressing techniques for displaying gray shades in passive matrix liquid crystal displays (LCDs). Amplitude modulation [1], pulse height modulation [2], successive approximation techniques [3,4] and wavelets based techniques [5-7] are some of the techniques that can be used to display gray shades. Grayscale to grayscale response times i.e. the time taken to switch from one arbitrary gray shade to another depends on the initial and final gray shades in these techniques. It is preferable to have uniform switching times between gray scales to preserve color purity of images and avoid motion artifacts. Almost uniform response times are achieved when pixels are switched from one arbitrary gray shade to another if the display is scanned with DCT based addressing technique that is proposed in this paper.

2. Discrete Cosine Transform

Discrete cosine transform is a subset of discrete Fourier transform. A function is expressed as a sum of cosine functions of several frequencies in discrete cosine transform (DCT) as compared to expressing it with sine and cosine functions in discrete Fourier transform (DFT). A DCT of a signal $s(n)$ is obtained as follows:

$$CT(k) = c(k) \sum_{n=0}^{N-1} s(n) \cdot \cos\left(\frac{\pi(2n+1)k}{2N}\right) \quad (1)$$

Wherein: $c(0) = \sqrt{\frac{1}{N}}$ and $c(k) = \sqrt{\frac{2}{N}}$ for $1 \leq k \leq N-1$.

DCT can also be represented as an orthogonal matrix and a DCT matrix of order 4 is shown in the following equation.

$$\frac{1}{\sqrt{2}} \begin{bmatrix} 0.7071 & 0.7071 & 0.7071 & 0.7071 \\ 0.9238 & 0.3827 & -0.3827 & -0.9238 \\ 0.7071 & -0.7071 & -0.7071 & 0.7071 \\ 0.3827 & -0.9238 & 0.9238 & -0.3827 \end{bmatrix} \quad (2)$$

The technique is demonstrated for 8 gray shades. It is adequate to have three discrete functions to multiplex the three bits of gray shades. The orthogonal matrix in (2) is modified to multiplex 3-bits of gray shade as discussed in the next section.

2.1 Modified Discrete Cosine Transform

Although any 3 of the 4 rows of the orthogonal matrix in equation (2) can be used to multiplex the three bits, we have chosen the last 3 rows because they are DC free. Hence, a DC free operation is achieved within a scan i.e., 4N time intervals instead of 8N time intervals that will be necessary if the 1st row is used for scanning the display. A 3x4 orthogonal matrix that is a subset of the DCT matrix of order 4 is shown in equation (3).

$$\begin{bmatrix} 0.9238 & 0.3827 & -0.3827 & -0.9238 \\ 0.7071 & -0.7071 & -0.7071 & 0.7071 \\ 0.3827 & -0.9238 & 0.9238 & -0.3827 \end{bmatrix} \quad (3)$$

Rows of the orthogonal matrix are suitably scaled so that the energies of waveforms correspond to the bit weight of the gray shade data. The modified orthogonal matrix is given by

$$\begin{bmatrix} 1 & -1 & -1 & 1 \\ 0.9238 & 0.3827 & -0.3827 & -0.9238 \\ 0.2706 & -0.6532 & 0.6532 & -0.2706 \end{bmatrix} \quad (4)$$

Here, the energy of the waveform corresponding to the first row is

$$1^2 + (-1)^2 + (-1)^2 + 1^2 = 4. \quad (5)$$

Similarly, the energy of the waveforms corresponding to the second and the third rows are as follows:

$$2(0.9238)^2 + 2(0.3827)^2 = 2 \quad (6)$$

$$2(0.2706)^2 + 2(0.6532)^2 = 1. \quad (7)$$

The waveform corresponding to the first row is used to multiplex the most significant bit because it has the highest energy. Waveforms corresponding to the rows 2 and 3 are used to multiplex the next significant bit and the least significant bit respectively. The process of scanning a matrix display is described in the next section.

3. Scanning the Matrix Display

Consider a matrix display having N rows and M columns with picture-elements (pixels) located at the intersection of the rows and columns. The matrix display may be scanned either by selecting the row electrodes or the column electrodes. The electrodes that are used for scanning the display are called the scanning electrodes and the electrodes that are orthogonal to the scanning electrodes are referred to as the data electrodes. Row electrodes are the scanning electrodes and column electrodes are the data electrodes in our prototype. These scanning electrodes are arranged to form about (N/s) sets of scanning electrodes each consisting of s electrodes where N corresponds to the number of rows in the matrix display. Columns of the orthogonal matrix are referred to as the select vectors because the row electrodes are selected with voltages corresponding to its elements. One of the

sets is selected at a time by applying voltages that are proportional to the elements of the select vector. Each set is formed with 4 rows in our prototype to reduce the hardware complexity of the controller, although just 3 rows can be selected simultaneously with three discrete cosine functions in the matrix of (4). The orthogonal matrix in (4) is modified to a matrix of order 4 by introducing a row consisting of 0 as its elements. The modified matrix is shown in (8). It allows using a simple binary counter to generate address for the bit-mapped memory and latch signal for the drivers.

$$\begin{bmatrix} 1 & -1 & -1 & 1 \\ 0.9238 & 0.3827 & -0.3827 & -0.9238 \\ 0.2706 & -0.6532 & 0.6532 & -0.2706 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (8)$$

The prototype has a display with 32 rows that form 8 sets of rows each having 4 rows. The four rows in a set are selected with voltages corresponding to a select vector i.e. a column in the orthogonal matrix. For example the voltages applied to the rows in the set are $+V_r, -0.9238 V_r, -0.2706 V_r$ and 0 that correspond to the fourth column in the matrix (8). Data voltages are also applied simultaneously with the select voltages and the data voltage is computed as shown in (9).

$$\begin{bmatrix} 1 \\ -0.9238 \\ -0.2706 \\ 0 \end{bmatrix} \begin{bmatrix} d_3 \\ d_2 \\ d_1 \\ x \end{bmatrix} V_c, \quad \text{Where in } x \text{ implies "don't care"} \quad (9)$$

The data corresponding to the most significant bit (MSB) is used for the first row because the discrete sequence in row-1 of the orthogonal matrix has the maximum energy that corresponds to the MSB. The middle bit (MISB) and the least significant bit (LSB) are used for the second and third rows of the selected group because the elements of the second and third rows of the orthogonal matrix correspond to the MISB and LSB respectively. The fourth row in the set is not selected just as the remaining 28 non-selected rows in the matrix display and therefore it is not necessary to have the gray shade bit of the pixel located in the fourth row to compute the column voltage. Let the gray shade of the pixel located at the intersection of row and column be as given by (10).

$$g_{i,j} = \sum_{k=0}^2 2^k d_{k,i,j} \quad (10)$$

Gray shade bits are assigned either +1 or -1 depending on the logic value of the bit as shown in equation (11).

$$d_{k,i,j} = \begin{cases} +1 & \forall \text{ Logic } = 0 \\ -1 & \forall \text{ Logic } = 1 \end{cases} \quad (11)$$

Value corresponding to the three bits of gray shades will range from -7 to $+7$, when these values in (11) are assigned to the bits. Energy delivered to the pixels in the first row of the selected set will be proportional to the binary weight of the MSB when the set is selected with the four select vectors in (8). Similarly, the pixels in second and third rows will get energies that are proportional to the middle and the least significant bits of the gray shades. The

fourth row of the selected set is like any other non-selected row and has been included in the set to simplify generating address to access data from the memory. Energy corresponding to other bits can be delivered to the pixels by rotating the rows of the orthogonal matrix as shown in (12).

$$\begin{bmatrix} 0.9238 & 0.3827 & -0.3827 & -0.9238 \\ 0.2706 & -0.6532 & 0.6532 & -0.2706 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad (12)$$

Pixels in the first row of the selected set will get voltages corresponding to middle bit where as the pixels in second and fourth rows will get voltages that correspond to the LSB and MSB respectively. All the pixels in the display get addressed once when all the sets are selected with 4 select vectors and their rotated versions i.e. all the rows are selected with the three discrete cosine sequences once. It can be achieved by several ways. For example a set of rows can be selected with all the 16 select vectors during 16 consecutive time intervals and the other sets can be selected sequentially one after another. Here, all the 12 select pulses are bunched within 16 time intervals. On the other extreme, one could select a set with a select vector and move on to another set and select it with another select vector taking care that all the sets are selected with all the select vectors during a cycle. The 12 select pulses will be distributed in time with this approach and therefore it is better suited to reduce flicker and suppress frame response phenomenon.

The root mean square (RMS) voltages across an ON pixel and an OFF pixel are given by equations in (13) and (14) respectively.

$$V_{ON}(RMS) = \sqrt{\frac{7(V_r^2 + 2V_r V_c + N V_c^2)}{4N}} \quad (13)$$

$$V_{OFF}(RMS) = \sqrt{\frac{7(V_r^2 - 2V_r V_c + N V_c^2)}{4N}} \quad (14)$$

High selection ratio is essential for good contrast in displays. It is a maximum when: $(V_r/V_c) = \sqrt{N}$ and the maximum selection ratio is $(V_{ON}/V_{OFF}) = \sqrt{\left(\frac{\sqrt{N}+1}{\sqrt{N}-1}\right)}$. (15)

4. Implementation

The technique is demonstrated with a 32x32 matrix twisted nematic (TN) LCD. Row waveforms have 11 voltage levels, but it is adequate to have 3 select and a non-select voltage at a time. Drivers that are capable of applying 1-of-4 voltages can be used to apply the row waveforms. Off the shelf drivers that are capable of applying 1-of-8 voltages are used along with some multiplexers as shown in Figure 1. Just eight voltages out of 16 voltages are necessary at any time, and drivers that are capable of selecting 1-of-8 voltages are used along with eight 2:1 analog type multiplexers as shown in Figure 2. A photograph of the prototype is shown in Figure 3. Display is refreshed at 50 Hz and the minimum frequency to avoid flicker was 40 Hz. Typical addressing waveforms are shown in Figure 4. Plots of RMS voltage across pixels that are driven to the eight gray shades vs. the supply voltage of the drivers are shown in Figure 5. Light transmission through the pixel when the pixel is switched from one grayscale to another is shown in Figure 6. Grayscale to

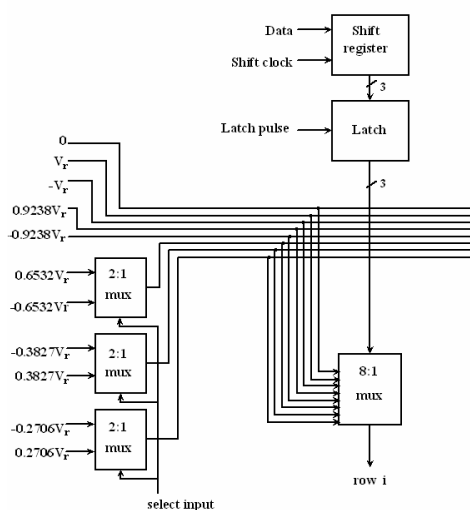


Figure 1. Row waveforms have 11 voltages. Row drivers select 1-of-8 voltages; 3- voltages are selected from 6 voltages using three 2:1 analog multiplexers that are common to all stages of row drivers as shown in here.

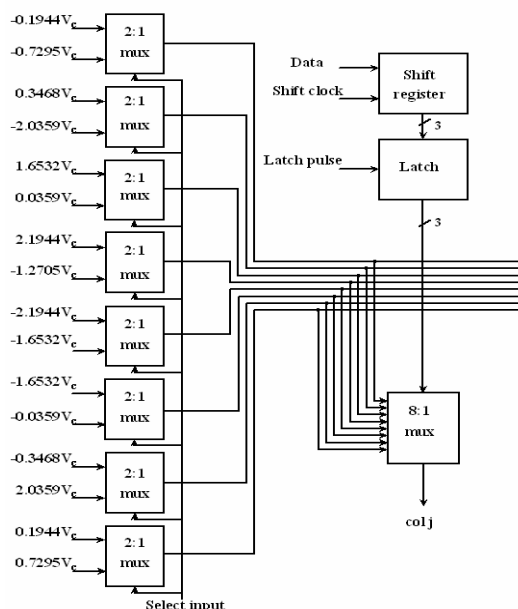


Figure 2. Column (data) waveforms have 16 voltages. Drivers that are capable of applying 1-of-8 voltages are used along with eight 2:1 analog multiplexers to select 8 of 16 voltages depending upon the select vector.

grayscale response times of the display is shown in Table 1. LC mixture RO-TN-403 having a threshold voltage of 1.33 volts is used in the display with a cell thickness of 4-micrometers. It is important to note that the display is not optimized for fast response. Note that the entries in upper-right triangle in the table are rise times, and those in lower-left triangle of the table are the fall times. Values within the parenthesis correspond to ideal

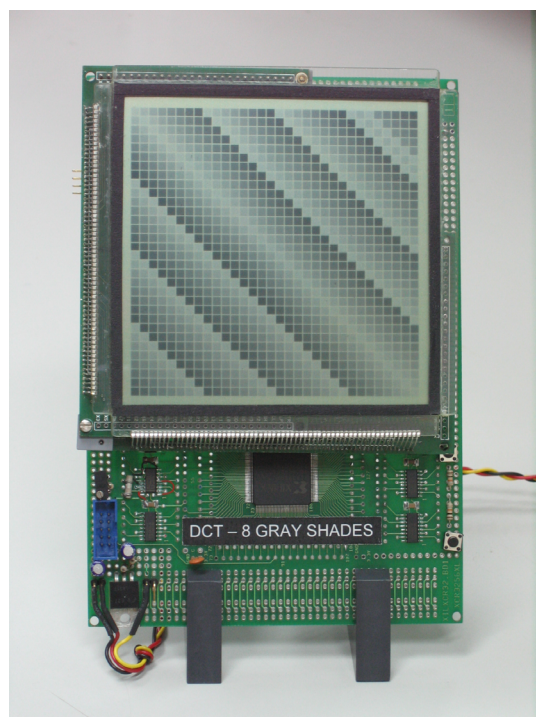


Figure 3. Photograph of the prototype that uses DCT to display eight gray shades.

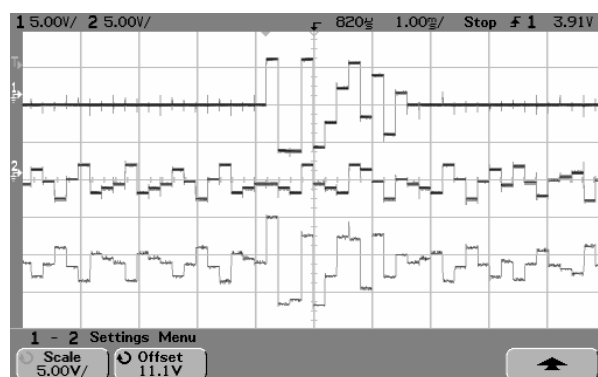


Figure 4. Addressing waveforms (from top): row waveform, column waveform and the waveform across the pixel respectively.

response times that were measured by applying square waveforms of RMS values that are obtained when 32 rows are multiplexed. It is important to note that the switching times of the multiplexed display is almost same as that obtained by driving the pixel with simple square waveforms having same RMS values. Hence, the response times are not affected if the matrix is scanned with the discrete cosine function.

5. Impact

Uniform response times are achieved in passive matrix display and the response time is almost independent of the initial and final gray shades. Uniform gray shade response times will improve the color purity of pixels in color displays and eliminate motion related artifacts in moving images.

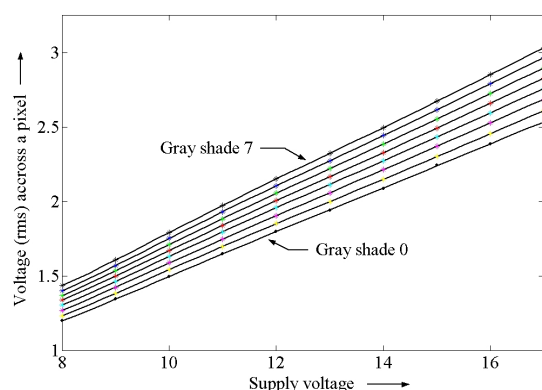


Figure 5. RMS voltage across pixel vs. supply voltage.

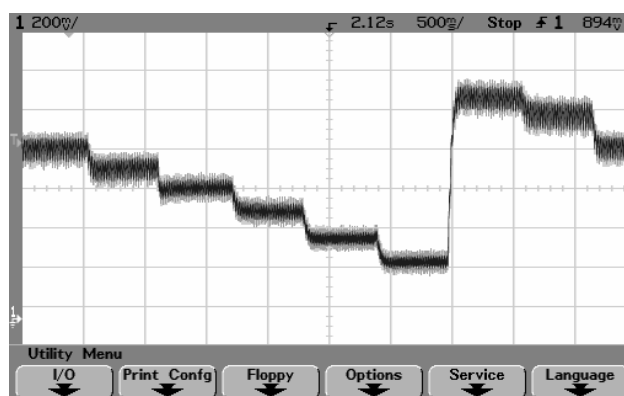


Figure 6. Light transmission vs. time when a pixel is switched to different gray shades.

Table 1. Response times-gray shade to gray shade (upper triangle: rise times, lower triangle: fall times and values with in the parenthesis correspond to response time obtained by square waves i.e., non-multiplexed condition).

RMS voltages	1.33 V	1.37 V	1.41V	1.45V	1.48V	1.52V	1.56V	1.59V
1.33V	X	68 (70)	65(60)	68 (61)	64 (59)	65(58)	65 (57)	67 (53)
1.37V	68 (70)	X	67 (67)	64 (59)	62 (59)	62 (60)	64 (54)	65 (55)
1.41V	60 (65)	66 (69)	X	60 (64)	61(58)	60 (63)	62 (57)	58 (57)
1.45V	64 (65)	62 (63)	64 (66)	X	60 (64)	58 (60)	60 (58)	60 (56)
1.48V	63 (64)	60 (63)	55 (62)	60 (65)	X	56 (65)	50 (57)	55 (59)
1.52V	60 (63)	60 (60)	58 (63)	56 (64)	60 (64)	X	60 (61)	52 (61)
1.56V	64 (61)	65 (61)	60 (61)	58 (59)	56 (57)	62 (61)	X	55 (58)
1.59V	68 (60)	64 (63)	64 (62)	62 (61)	60 (64)	62 (63)	56 (56)	X

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7. References

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