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(54) **METHODS FOR DRIVING ELECTRO-OPTIC DISPLAYS**

VERFAHREN ZUM ANTREIBEN ELEKTRO-OPTISCHER ANZEIGEN

PROCEDES D'ATTAQUE D'AFFICHEURS ELECTRO-OPTIQUES

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(73) Proprietor: **E Ink Corporation**
Cambridge, MA 02138-1002 (US)

(72) Inventors:
• **AMUNDSON, Karl, R.**
Cambridge, MA 02138 (US)
• **ZEHNER, Robert, W.**
Cambridge, MA 02140 (US)
• **KNAIAN, Ara**
Newton, MA 02465 (US)

• **ZION, Benjamin**
State College, PA 16801 (US)

(74) Representative: **Cole, David John**
46 Kirkhill Gardens
West Greenlees Estate
Cambuslang
GB-Glasgow G72 8EZ (GB)

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Description

[0001] This invention relates to methods for driving electro-optic displays. The methods of the present invention are especially, though not exclusively, intended for use in driving bistable electrophoretic displays.

[0002] This application is closely related to International Applications PCT/US02/37241 (Publication No. WO 03/044765) and PCT/US2004/10091, and the following description will assume that the reader is familiar with the contents of these documents.

[0003] The term "electro-optic" as applied to a material or a display, is used herein in its conventional meaning in the imaging art to refer to a material having first and second display states differing in at least one optical property, the material being changed from its first to its second display state by application of an electric field to the material. Although the optical property is typically color perceptible to the human eye, it may be another optical property, such as optical transmission, reflectance, luminescence or, in the case of displays intended for machine reading, pseudo-color in the sense of a change in reflectance of electromagnetic wavelengths outside the visible range.

[0004] The term "gray state" is used herein in its conventional meaning in the imaging art to refer to a state intermediate two extreme optical states of a pixel, and does not necessarily imply a black-white transition between these two extreme states. For example, several of the patents and published applications referred to below describe electrophoretic displays in which the extreme states are white and deep blue, so that an intermediate "gray state" would actually be pale blue. Indeed, as already mentioned the transition between the two extreme states may not be a color change at all.

[0005] The terms "bistable" and "bistability" are used herein in their conventional meaning in the imaging art to refer to displays comprising display elements having first and second display states differing in at least one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element. It is shown in International Application WO 02/079869 that some particle-based electrophoretic displays capable of gray scale are stable not only in their extreme black and white states but also in their intermediate gray states, and the same is true of some other types of electro-optic displays. This type of display is properly called "multi-stable" rather than bistable, although for convenience the term "bistable" may be used herein to cover both bistable and multi-stable displays.

[0006] The term "impulse" is used herein in its conventional meaning in the imaging art of the integral of voltage with respect to time. However, some bistable electro-optic

media act as charge transducers, and with such media an alternative definition of impulse, namely the integral of current over time (which is equal to the total charge applied) may be used. The appropriate definition of impulse should be used, depending on whether the medium acts as a voltage-time impulse transducer or a charge impulse transducer.

[0007] As described in the aforementioned WO 03/044765 and PCT/US2004/10091, several types of electro-optic displays are known, for example the rotating bichromal member type as described, for example, in U.S. Patents Nos. 5,808,783; 5,777,782; 5,760,761; 6,054,071; 6,055,091; 6,097,531; 6,128,124; 6,137,467; and 6,147,791 and the electrochromic type; see, for example O'Regan, B., et al., *Nature* 1991, 353, 737; and Wood, D., *Information Display*, 18(3), 24 (March 2002). See also Bach, U., et al., *Adv. Mater.*, 2002, 14(11), 845. Nanochromic films of this type are also described, for example, in U.S. Patent No. 6,301,038, International Application Publication No. WO 01/27690, and in U.S. Patent Application 2003/0214695.

[0008] Another type of electro-optic display, which has been the subject of intense research and development for a number of years, is the particle-based electrophoretic display. Numerous patents and applications assigned to or in the names of the Massachusetts Institute of Technology (MIT) and E Ink Corporation describe such displays; see for example, U.S. Patents Nos. 5,930,026; 5,961,804; 6,017,584; 6,067,185; 6,118,426; 6,120,588; 6,120,839; 6,124,851; 6,130,773; 6,130,774; 6,172,798; 6,177,921; 6,232,950; 6,249,721; 6,252,564; 6,262,706; 6,262,833; 6,300,932; 6,312,304; 6,312,971; 6,323,989; 6,327,072; 6,376,828; 6,377,387; 6,392,785; 6,392,786; 6,413,790; 6,422,687; 6,445,374; 6,445,489; 6,459,418; 6,473,072; 6,480,182; 6,498,114; 6,504,524; 6,506,438; 6,512,354; 6,515,649; 6,518,949; 6,521,489; 6,531,997; 6,535,197; 6,538,801; 6,545,291; 6,580,545; 6,639,578; 6,652,075; 6,657,772; 6,664,944; 6,680,725; 6,683,333; 6,704,133; 6,710,540; 6,721,083; 6,724,519; and 6,727,881; and U.S. Patent Applications Publication Nos. 2002/0019081; 2002/0021270; 2002/0053900; 2002/0060321; 2002/0063661; 2002/0063677; 2002/0090980; 2002/0106847; 2002/0113770; 2002/0130832; 2002/0131147; 2002/0145792; 2002/0171910; 2002/0180687; 2002/0180688; 2002/0185378; 2003/0011560; 2003/0011868; 2003/0020844; 2003/0025855; 2003/0034949; 2003/0038755; 2003/0053189; 2003/0102858; 2003/0132908; 2003/0137521; 2003/0137717; 2003/0151702; 2003/0189749; 2003/0214695; 2003/0214697; 2003/0222315; 2004/0008398; 2004/0012839; 2004/0014265; 2004/0027327; 2004/0075634; and 2004/0094422; and International Applications Publication Nos. WO 99/67678; WO 00/05704; WO 00/38000; WO 00/38001; WO 00/36560; WO 00/67110; WO 00/67327; WO 01/07961; WO 01/08241; WO 03/092077; WO 03/107315; WO 2004/017035; and WO 2004/023202.

[0009] Many of the aforementioned patents and applications recognize that the walls surrounding the discrete microcapsules in an encapsulated electrophoretic medium could be replaced by a continuous phase, thus producing a so-called "polymer-dispersed electrophoretic display" in which the electrophoretic medium comprises a plurality of discrete droplets of an electrophoretic fluid and a continuous phase of a polymeric material, and that the discrete droplets of electrophoretic fluid within such a polymer-dispersed electrophoretic display may be regarded as capsules or microcapsules even though no discrete capsule membrane is associated with each individual droplet; see for example, the aforementioned 2002/0131147. Accordingly, for purposes of the present application, such polymer-dispersed electrophoretic media are regarded as sub-species of encapsulated electrophoretic media.

[0010] A related type of electrophoretic display is a so-called "microcell electrophoretic display". In a microcell electrophoretic display, the charged particles and the suspending fluid are not encapsulated within capsules but instead are retained within a plurality of cavities formed within a carrier medium, typically a polymeric film. See, for example, International Application Publication No. WO 02/01281, and U.S. Patent Application Publication No. 2002/0075556, both assigned to Sipix Imaging, Inc.

[0011] Although electrophoretic media are often opaque (since, for example, in many electrophoretic media, the particles substantially block transmission of visible light through the display) and operate in a reflective mode, many electrophoretic displays can be made to operate in a so-called "shutter mode" in which one display state is substantially opaque and one is light-transmissive. See, for example, the aforementioned U.S. Patents Nos. 6,130,774 and 6,172,798, and U.S. Patents Nos. 5,872,552; 6,144,361; 6,271,823; 6,225,971; and 6,184,856. Dielectrophoretic displays, which are similar to electrophoretic displays but rely upon variations in electric field strength, can operate in a similar mode; see U.S. Patent No. 4,418,346. Other types of electro-optic displays may also be capable of operating in shutter mode.

[0012] The bistable or multi-stable behavior of particle-based electrophoretic displays, and other electro-optic displays displaying similar behavior (such displays may hereinafter for convenience be referred to as "impulse driven displays"), is in marked contrast to that of conventional liquid crystal ("LC") displays. Twisted nematic liquid crystals act are not bi- or multi-stable but act as voltage transducers, so that applying a given electric field to a pixel of such a display produces a specific gray level at the pixel, regardless of the gray level previously present at the pixel. Furthermore, LC displays are only driven in one direction (from non-transmissive or "dark" to transmissive or "light"), the reverse transition from a lighter state to a darker one being effected by reducing or eliminating the electric field. Finally, the gray level of a pixel

of an LC display is not sensitive to the polarity of the electric field, only to its magnitude, and indeed for technical reasons commercial LC displays usually reverse the polarity of the driving field at frequent intervals. In contrast, bistable electro-optic displays act, to a first approximation, as impulse transducers, so that the final state of a pixel depends not only upon the electric field applied and the time for which this field is applied, but also upon the state of the pixel prior to the application of the electric field.

[0013] It might at first appear that the ideal method for addressing such an impulse-driven electro-optic display would be so-called "general grayscale image flow" in which a controller arranges each writing of an image so that each pixel transitions directly from its initial gray level to its final gray level. However, inevitably there is some error in writing images on an impulse-driven display. Some such errors encountered in practice include:

(a) *Prior State Dependence*; With at least some electro-optic media; the impulse required to switch a pixel to a new optical state depends not only on the current and desired optical state, but also on the previous optical states of the pixel.

(b) *Dwell Time Dependence*; With at least some electro-optic media, the impulse required to switch a pixel to a new optical state depends on the time that the pixel has spent in its various optical states. The precise nature of this dependence is not well understood, but in general, more impulse is required that longer the pixel has been in its current optical state.

(c) *Temperature Dependence*; The impulse required to switch a pixel to a new optical state depends heavily on temperature.

(d) *Humidity Dependency*; The impulse required to switch a pixel to a new optical state depends, with at least some types of electro-optic media, on the ambient humidity.

(e) *Mechanical Uniformity*; The impulse required to switch a pixel to a new optical state may be affected by mechanical variations in the display, for example variations in the thickness of an electro-optic medium or an associated lamination adhesive. Other types of mechanical non-uniformity may arise from inevitable variations between different manufacturing batches of medium, manufacturing tolerances and materials variations.

(f) *Voltage Errors*; The actual impulse applied to a pixel will inevitably differ slightly from that theoretically applied because of unavoidable slight errors in the voltages delivered by drivers.

[0014] As described in the aforementioned WO 03/044765 and PCT/US2004/10091, general grayscale image flow suffers from an "accumulation of errors" phenomenon which may produce deviations in gray levels apparent to the average observer on certain types of images. This accumulation of errors phenomenon applies

to errors of all the types listed above. As described in the aforementioned 2003/0137521, compensating for such errors is possible, but only to a limited degree of precision. Thus, general grayscale image flow requires very precise control of applied impulse to give good results, and empirically it has been found that, in the present state of the technology of electro-optic displays, general grayscale image flow is infeasible in a commercial display.

[0015] Almost all electro-optic medium have a built-in resetting (error limiting) mechanism, namely their extreme (typically black and white) optical states, which function as "optical rails". After a specific impulse has been applied to a pixel of an electro-optic display, that pixel cannot get any whiter (or blacker). For example, in an encapsulated electrophoretic display, after a specific impulse has been applied, all the electrophoretic particles are forced against one another or against the capsule wall, and cannot move further, thus producing a limiting optical state or optical rail. Because there is a distribution of electrophoretic particle sizes and charges in such a medium, some particles hit the rails before others, creating a "soft rails" phenomenon, whereby the impulse precision required is reduced when the final optical state of a transition approaches the extreme black and white states, whereas the optical precision required increases dramatically in transitions ending near the middle of the optical range of the pixel.

[0016] Various types of drive schemes for electro-optic displays are known which take advantage of optical rails. For example, Figures 9 and 10 of the aforementioned WO 03/044765, and the related description, describe a "slide show" drive scheme in which the entire display is driven to both optical rails before any new image is written. Such a slide show drive scheme produces accurate grayscale levels, but the flashing of the display as it is driven to the optical rails is distracting to the viewer. It has also been suggested (see U.S. Patent No. 6,531,997) that a similar drive scheme be employed in which only the pixels, whose optical states need to be changed in the new image, be driven to the optical rails. However, this type of "limited slide show" drive scheme is, if anything, even more distracting to the viewer, since the solid flashing of a normal slide show drive scheme is replaced by image dependent flashing, in which features of the old image and the new image flash in reverse color on the screen before the new image is written.

[0017] Obviously, a pure general grayscale image flow drive scheme cannot rely upon using the optical rails to prevent errors in gray levels since in such a drive scheme any given pixel can undergo an infinitely large number of changes in gray level without ever touching either optical rail.

[0018] This invention seeks to provide methods for achieving fine control of gray levels in displays driven by pulse width modulation.

[0019] When driving an active matrix display having a bistable electro-optic medium to write gray scale images thereon, it is desirable to be able to apply a precise

amount of impulse to each pixel, so as to achieve accurate control of the gray scale displayed. The driving method used may rely modulation of the voltage applied to each pixel and/or modulation of the "width" (duration) for which the voltage is applied. Since voltage modulated drivers and their associated power supplies are relatively costly, pulse width modulation is commercially attractive. However, during the scanning of an active matrix display using such pulse width modulation, conventional driver circuitry only allows one to apply a single voltage to any given pixel during any one scan of the matrix. Consequently, pulse width modulation driving of active matrix displays is effected by scanning the matrix multiple times, with the drive voltage being applied during none, some or all of the scans, depending upon the change desired in the gray level of the specific pixel. Each scan may be regarded as a frame of the drive waveform, with the complete addressing pulse being a superframe formed by a plurality of successive frames. It should be noted that, although the drive voltage is only applied to any specific pixel electrode for one line address time during each scan, the drive voltage persists on the pixel electrodes during the time between successive selections of the same line, only slowly decaying, so that the pixel is driven between successive selections of the same line.

[0020] As already mentioned, each row of the matrix needs to be individually selected during each frame so that for high resolution displays (for example, 800 x 600 pixel displays) in practice the frame rate cannot exceed about 50 to 100 Hz; thus each frame typically lasts 10 to 20 ms. Frames of this length lead to difficulties in fine control of gray scale with many fast switching electro-optic medium. For example, some encapsulated electrophoretic media substantially complete a switch between their extreme optical states (a transition of about 30 L* units) within about 100 ms, and with such a medium a 20 ms frame corresponds to a gray scale shift of about 6 L* units. Such a shift is too large for accurate control of gray scale; the human eye is sensitive to differences in gray levels of about 1 L* unit, and controlling the impulse only in graduations equivalent to about 6 L* units is likely to give rise to visible artifacts, such as "ghosting" due to prior state dependence of the electro-optic medium. More specifically, ghosting may be experienced because, as discussed in some of the aforementioned patents and applications, the variation of gray level with applied impulse is not linear, and the total impulse needed for any specific change in gray level may vary with the time at which the impulse is applied and the intervening gray levels. For example, in a simple 4 gray level (2 bit) display having gray levels 0 (black), 1 (dark gray), 2 (light gray) and 3 (white), driven by a simple pulse width modulation drive scheme, these non-linearities may result in the actual gray level achieved after a notional 0-2 transition being different from the gray level achieved after a notional 1-2 transition, with the production of highly undesirable visual artifacts. This invention provides methods for achieving fine control of gray levels in displays

driven by pulse width modulation, thus avoiding the aforementioned problems.

[0021] This invention provides a method for driving an electro-optic display having a plurality of pixels divided into a plurality of groups, wherein a complete rewriting of the display is achieved by a pulse width modulation method by scanning the matrix a plurality of times in respective frame periods being equal in length, each time supplying each pixel with either a drive voltage or a non-drive voltage. This method comprises:

- (a) selecting each of the plurality of groups of pixels in succession and applying to each of the pixels in the selected group either the drive voltage or the non-drive voltage, the scanning of all the groups of pixels being completed in a first frame period;
- (b) repeating the scanning of the groups of pixels during a second frame period equal in length to the first frame period; and
- (c) interrupting the scanning of the groups of pixels during a pause period between the first and second frame periods, this pause period having a length equal to a sub-multiple of the length of one of first and second frame periods.

[0022] This method may hereinafter for convenience be referred to as the "interrupted scanning" method of the present invention.

[0023] The interrupted scanning method may include multiple pause periods; thus the method may comprise scanning the groups of pixels during at least first, second and third frame periods, and interrupting the scanning of the groups of pixels during at least first and second pause periods between successive frame periods. The first, second and third frame periods may be substantially equal in length, and the total length of the pause periods be equal to one frame period or one frame period minus one pause period. Typically, in the interrupted scanning method, the pixels are arranged in a matrix having a plurality of rows and a plurality of columns with each pixel defined by the intersection of a given row and a given column, and each group of pixels comprises one row or one column of the matrix. The interrupted scanning method is preferably DC balanced, i.e., the scanning of the display is preferably effected such that, for any series of transitions undergone by a pixel, the integral of the applied voltage with time is bounded.

[0024] The method of the present invention as described above may be carried out with any of the aforementioned types of electro-optic media. Thus, the method of the present invention may be used with electro-optic displays comprising an electrochromic or rotating bichromal member electro-optic medium, an encapsulated electrophoretic medium, or a microcell electrophoretic medium. Other types of electro-optic media may also be employed.

[0025] As mentioned above, the present invention makes use of pause periods between adjacent frames

of a transition; such pause periods are discussed in more detail below with reference to the interrupted scanning method of the present invention. Typically, in an active matrix display, the pixels are divided into a series of groups (normally a plurality of rows), each of these plurality of groups is selected in succession (i.e., typically the rows of the matrix are scanned) and there is applied to each of the pixels in the selected group either a drive voltage or a non-drive voltage. The scanning of all the groups of pixels is completed within a frame period. The scanning of the groups of pixels is repeated, and, in a typical electro-optic display, the scanning will be repeated more than once during the group of frames (conveniently referred to as a superframe) required for a complete rewriting of the display. Normally, a fixed scan rate is used for updating, for example 50 Hz, which allows for 20 msec frames. However, this frame length may provide insufficient resolution for optimal waveform performance. In many cases, frames of length $t/2$ are desirable, for example 10 msec frames in a normally 20 msec frame length waveform. It is possible to combine frames of differing delay times to generate a pulse resolution of $n/2$. To take one specific case a single frame of length $1.5 \cdot t$ may be inserted at the beginning of the waveform, and a similar frame at the end of the waveform (immediately before the terminating 0 V frame, which should occur at the ordinary frame rate and which is normally used at the end of the waveform to prevent undesirable effects caused by varying residual voltages on pixels). The two longer frames can be realized by simply adding a $0.5 \cdot t$ delay time between the scanning of two adjacent frames. The waveform would then have the structure:

[0026] t ms frame : $t/2$ ms delay : t ms frame [...] t ms frame : $t/2$ ms delay : t ms frame (all outputs to 0V)

[0027] For a normal frame length of 20 msec, the initial and final frames plus their respective delays would amount to 30 msec each.

[0028] Using this waveform, structure, the initial and final pulses are allowed to vary by 10 msec in length, by using the following algorithm:

- (a) If the length of the initial pulse is evenly divisible by t , then the first frame consists of a 0 V drive, and a corresponding number of frames of t ms are activated to achieve the desired pulse length; or
- (b) If the length of the initial pulse leaves a remainder of $t/2$ when divided by t , then the first frame of $1.5 \cdot t$ is active, and a corresponding number of t msec frames following the initial frame are activated to achieve the desired pulse length.

[0029] The same algorithm is followed for the final pulse.

[0030] Since the improvements provided by the present invention can be applied to a wide variety of methods for driving electro-optic displays described in the aforementioned WO 03/044765 and PCT/US2004/10091, the following description will as-

some familiarity with the basic driving methods shown in Figures 1-10 of WO 03/044765 and the related description. In particular Figures 9 and 10 of this application describe so-called uncompensated n-prepulse slide show (n-PP SS) waveforms having three basic sections. First, the pixels are erased to a uniform optical state, typically either white or black. Next, the pixels are driven back and forth between two optical states, again typically white and black. Finally, the pixel is addressed to a new optical state, which may be one of several gray states. The final (or writing) pulse is referred to as the addressing pulse, and the other pulses (the first (or erasing) pulse and the intervening (or blanking) pulses) are collectively referred to as prepulses

[0031] One major shortcoming of this type of waveform is that it has large-amplitude optical flashes between images. This can be improved by shifting the update sequence by one superframe time for half of the pixels, and interleaving the pixels at high resolution, as discussed in WO 03/044765 with reference to Figures 9 and 10 thereof. Possible patterns include every other row, every other column, or a checkerboard pattern. Note, this does not mean using the opposite polarity, i.e. "from black" versus "from white", since this would result in non-matching gray scales on neighboring pixels. Instead, this can be accomplished by delaying the start of the update by one "superframe" (a grouping of frames equivalent to the maximum length of a black-white update) for half of the pixels (i.e. the first set of pixels completes the erase pulse, then the second set of pixels begin the erase pulse as the first set of pixels begin the first blanking pulse). This will require the addition of one superframe for the total update time, to allow for this synchronization.

[0032] As already mentioned, this invention provides an "interrupted scanning" method for driving a bistable electrophoretic display having a plurality of pixels divided into a plurality of groups. The optical state of a pixel is controlled by a pulse width modulation method by scanning the matrix a plurality of time. The method comprises selecting each of the plurality of groups of pixels in succession and applying to each of the pixels in the selected group either a drive voltage or a non-drive voltage, the scanning of all the groups of pixels being completed in a first frame period. The scanning of the groups of pixels is repeated during a second frame period (it being understood that any specific pixel may have the drive voltage applied during the first frame period and the non-drive voltage applied during the second frame period, or *vice versa*). In the interrupted scanning method invention, the scanning of the groups of pixels is interrupted during a pause period between the first and second frame periods, this pause period being not longer than the first or second frame period. In this method, the first and second frame periods are equal in length, and the length of the pause period is a sub-multiple (desirably, one half, one fourth etc.) of the length of one of the frame periods.

[0033] The interrupted scanning method may include multiple pause periods between different pairs of adja-

cent frame periods. Such multiple pause periods are preferably of substantially equal length, and the total length the multiple pause periods is preferably equal to either one complete frame period, or equal to one frame period less one pause period. For example, as discussed in more detail below, one embodiment of the first method might use multiple 20 ms frame periods, and either three or four 5 ms pause periods.

[0034] In this interrupted scanning method, the groups of pixels will of course typically be the rows of a conventional row/column active matrix pixel array. The interrupted scanning method comprises selecting each of the plurality of groups of pixels in succession (i.e., typically, scanning the rows of the matrix) and applying to each of the pixels in the selected group either a drive voltage or a non-drive voltage, the scanning of all the groups of pixels being completed in a first frame period. The scanning of the groups of pixels is repeated, and in a typical electro-optic display, the scanning will be repeated more than once during the superframe required for a complete rewriting of the display. The scanning of the groups of pixels is interrupted during a pause period between the first and second frame periods, this pause period being not longer than the first or second frame period.

[0035] Although a drive voltage is only applied to any specific pixel electrode for one line address time during each scan, the drive voltage persists on the pixel electrodes during the time between successive selections of the same line, only slowly decaying, so that the pixel continues to driven during the time when other lines of the matrix are being selected, and the interrupted scanning method relies upon this continued driving of the pixel during its "non-selected" time. Ignoring for the moment the slow decay of the voltage on the pixel electrode during its non-selected time, a pixel which is set to the driving voltage during the frame period immediately preceding the pause period will continue to experience the driving voltage during the pause period, so that for such a pixel the preceding frame period is in effect lengthened by the length of the pause period. On the other hand, a pixel which is set to the non-driving (typically zero) voltage during the frame period immediately preceding the pause period will continue to experience the zero voltage during the pause period. It may be desirable to adjust the length of the pause period to allow for the slow decay of the voltage on the pixel electrode in order to ensure that the total impulse delivered to the pixel during the pause period has the desired value.

[0036] To take a simple example of the interrupted scanning method for purposes of illustration, consider a simple pulse width modulated drive scheme having a superframe consisting of a plurality of (say 10) 20 ms frames. Typically, the last frame of the superframe will set all pixels to the non-driving voltage, since bistable electro-optic displays are normally only driven when the displayed image is to be changed, or at relatively long intervals when it is deemed desirable to refresh the displayed image, so that each superframe will typically be

followed by a lengthy period in which the display is not driven, and it is highly desirable to set all pixels to the non-driving voltage at the end of the superframe in order to prevent rapid changes in some pixels during this lengthy non-driven period. To modify such a drive scheme in accordance with the interrupted scanning method of the present invention, a 10 ms pause period may be inserted between two successive 20 ms frames, and this simple modification halves the maximum possible difference between the applied impulse and the impulse ideally needed to complete a given transition, thereby in practice approximately halving the maximum deviation in achieved gray scale level. The 10 ms pause period is conveniently inserted after the penultimate frame in each superframe but may be inserted at other points in the superframe if desired.

[0037] In practice, it is desirable, in this example, not only to insert the 10 ms pause period but also to insert one additional 20 ms frame into each superframe. The unmodified drive scheme enables one to apply to any given pixel impulses of:

0, 20, 40, 60...160, 180 units

where one impulse unit is defined as the impulse resulting from application of the driving voltage for 1 ms. Thus, the maximum difference between the available impulses and the ideal impulse for a given transition is 10 units. (Since the last frame of the superframe sets all pixels to the non-driving voltage, only the first nine frames of the superframe are available for application of the driving voltage.) As already explained, any pixel which is set to the driving voltage in the frame preceding the pause period continues to experience this driving voltage for a period equal to the frame period plus the pause period, and thus experiences an impulse of 30 units instead of 20 units for this frame. Accordingly, the modified drive scheme permits one to apply to any given pixel impulses of:

0, 20, 30, 40, 50, 60 units etc.

Insertion of the additional frame into the superframe is desirable to enable the modified drive scheme to deliver an impulse of exactly 180 units. Since any impulse which is an exact multiple of 20 units requires that the relevant pixel be set to the non-driving voltage during the frame preceding the pause period, achieving an impulse of exactly 180 units requires an 11-frame superframe, so that any pixel to receive the 180 impulse can be set to the driving voltage during 9 frames, to the non-driving voltage during the frame preceding the pause period, and (as always) to the non-driving voltage during the last frame of the superframe. Thus, when using the modified drive scheme, the maximum difference between the available impulses and the ideal impulse for a given transition is reduced to 5 units. (Although the modified drive scheme is not capable of applying an impulse of 10 units, in practice this is of little consequence. To produce reasonably

consistent gray scale levels, the number of available impulse levels has to be substantially larger than the number of gray levels of the display, so that it is unlikely that any gray scale transition will require an impulse as small as 10 units.)

[0038] The pause periods can of course be of any number and length required to achieve the desired control over the impulse applied. For example, instead of modifying the aforementioned drive scheme to include one 10 ms pause period, the drive scheme could be modified to include three 5 ms pause periods after different 20 ms drive frames, desirably with the addition to the drive scheme of three further 20 ms drive frames not followed by pause periods. This modified drive scheme permits one to apply to any given pixel impulses of:

0, 20, 25, 30, 35170, 175, 180 units

thereby reducing the maximum difference between the available impulses and the ideal impulse for a given transition is reduced to 2.5 units, a four-fold reduction as compared with the original unmodified drive scheme.

[0039] The preceding discussion of the interrupted scanning method has ignored the question of polarity of the applied impulses. As discussed above and in the aforementioned WO 03/044765, bistable electro-optic media require application of impulses of both polarities. In some drive schemes, such as slide show drive schemes, before a new image is written to the display, all the pixels of the display are first driven to one extreme optical state, either black or white, and thereafter the pixels are driven to their final gray states by impulses of a single polarity. Such drive schemes can be modified in accordance with the interrupted scanning method in the manner already described. Other drive schemes require application of impulses of both polarities to drive the pixels to their final gray states. The impulses of the two polarities may be applied in separate frames or impulses of the two polarities may be applied in the same frames, for example using a tri-level drive scheme in which the common front electrode is held at a voltage of $V/2$, while individual pixel electrodes are held at 0, $V/2$ or V . When the impulses of the two polarities are applied in separate frames, the interrupted scanning method is desirably effected by providing at least two separate pause periods, one following a frame in which impulses of one polarity are applied and the second following a frame in which impulses of the opposed polarity are applied. However, when using a drive scheme in which impulses of both polarities are applied in the same frames, the interrupted scanning method may make use of only a single pause period since, as will be apparent from the foregoing discussion, the effect of including a pause period after a frame is to increase the magnitude of the impulse applied to any pixel to which a driving voltage was applied in the frame, regardless of the polarity of this driving voltage.

[0040] Also as discussed in the aforementioned WO 03/044765 and above, many bistable electro-optic media

are desirably driven with drive schemes which achieve long term direct current (DC) balance, and such DC balance is conveniently effected using a drive scheme in which a DC balance section, which does not substantially change the gray level of the pixel, is applied before the main drive section, which does change the gray level, the two sections being chosen so that the algebraic sum of the impulses applied is zero or at least very small. If the main drive section is modified in accordance with the interrupted scanning method, it is highly desirable that the DC balance section be modified to prevent the additional impulses caused by the insertion of the pause periods accumulating to cause substantial DC imbalance. However, it is not necessary that the DC balance section be modified in a manner which is an exact mirror image of the modification of the main drive section, since the DC balance section can have gaps (zero voltage frames) and most electro-optic medium are not harmed by short term DC imbalances. Thus, in the drive scheme discussed above using a single 10 ms pause period inserted among ten 20 ms frames, DC balance can be achieved by making the first frame of the drive scheme 30 ms in duration. Applying or not applying a driving voltage to a pixel during this frame brings the overall impulse to a multiple of 20 units, so that this impulse can readily be balanced later. In the drive scheme using three 5 ms pause periods, the first two frames of the drive scheme can similarly be 25 and 30 ms in duration (in either order), again bringing the overall impulse to a multiple of 20 units.

[0041] From the foregoing description, it will be seen that the interrupted scanning method of the present invention requires a trade-off between increased addressing time caused by the need to include one additional frame in each superframe for each pause period inserted, and the improved control of impulse and hence gray scale produced by the method. However, the interrupted scanning method can provide very substantial improvement in impulse control with only modest increase in addressing time; for example, the drive scheme described above in which a superframe comprising ten 20 ms frames is modified to include three 5 ms pause periods yields a four-fold improvement in impulse accuracy at the cost of less than a 40 per cent increase in addressing time.

[0042] The method of the present invention may make use of various additional variations and techniques described in the aforementioned applications, especially the aforementioned WO 03/044765 and PCT/US2004/010091. It will be appreciated that in the overall waveform used to drive an electro-optic display, in at least some cases certain transitions may be effected in accordance with the present invention, while other transitions may not make use of the method of the present invention but may make use of other types of transitions described below. For example, the method of the present invention may make use of any one or more of:

non-contiguous addressing (see the aforementioned PCT/US2004/010091, Paragraphs [0142] to

[0234] and Figures 1-12);

DC balanced addressing, as partially discussed above (but see also the aforementioned PCT/US2004/010091, Paragraphs [0235] to [0260] and Figures 13-21);

defined region updating (see the aforementioned PCT/US2004/010091, Paragraphs [0261] to [0280]); compensation voltage addressing (see the aforementioned PCT/US2004/010091, Paragraphs [0284] to [0308] and Figure 22);

DTD integral reduction addressing (see the aforementioned PCT/US2004/010091, Paragraphs [0309] to [0326] and Figure 23); and

remnant voltage addressing (see the aforementioned WO 03/044,765, pages 59 to 62).

Claims

1. A method for driving a bistable active matrix electrophoretic display having a plurality of pixels divided into a plurality of groups, wherein a complete rewriting of the display is achieved by a pulse width modulation method by scanning the matrix a plurality of times in respective Frame periods being equal in length, each time supplying each pixel with either a drive voltage or a non-drive voltage, the method comprising:

(a) scanning the matrix by selecting each of the plurality of groups of pixels in succession and applying to each of the pixels in the selected group either the drive voltage or the non-drive voltage, the scanning of all the groups of pixels being completed in a first of said frame periods; and

(b) repeating the scanning of the groups of pixels during a second of said frame periods,

the method being **characterized by** interrupting the scanning of the groups of pixels during a pause period between the first and second frame periods, this pause period having a length equal to a sub-multiple of the length of one frame period.

2. A method according to claim 1 wherein the method comprises scanning the groups of pixels during at least first, second and third frame periods, and interrupting the scanning of the groups of pixels during at least first and second pause periods between successive frame periods.

3. A method according to claim 2 wherein the first, second and third frame periods are substantially equal in length, and the total length of the pause periods is equal to one frame period or one frame period minus one pause period.

4. A method according to claim 1 wherein the pixels are arranged in a matrix having a plurality of rows and a plurality of columns with each pixel defined by the intersection of a given row and a given column, and wherein each group of pixels comprises one row or one column of the matrix.
5. A method according to claim 1 wherein the electro-optic display comprises an encapsulated electrophoretic medium.
6. A method according to claim 1 wherein the electro-optic display comprises a microcell electrophoretic medium.

Patentansprüche

1. Verfahren zum Ansteuern einer bistabilen elektrophoretischen Aktivmatrixanzeige mit mehreren Pixeln, die in mehrere Gruppen aufgeteilt sind, wobei ein vollständiges Neubeschreiben der Anzeige durch ein Pulsweitenmodulationsverfahren durch mehrmaliges Scannen der Matrix in entsprechenden gleichlangen Bildperioden erreicht wird, wobei jedes Mal jedes Pixel mit entweder einer Ansteuerspannung oder einer Nicht-Ansteuerspannung versorgt wird, wobei das Verfahren Folgendes umfasst:
 - (a) Scannen der Matrix durch Auswählen jeder der mehreren Gruppen von Pixeln der Reihe nach und Anlegen entweder der Ansteuerspannung oder der Nicht-Ansteuerspannung an jedes der Pixel in der ausgewählten Gruppe, wobei das Scannen aller Gruppen von Pixeln in einer ersten der Bildperioden abgeschlossen wird; und
 - (b) Wiederholen des Scannens der Gruppen von Pixeln während einer zweiten der Bildperioden, wobei das Verfahren **gekennzeichnet ist durch** Unterbrechen des Scannens der Gruppe von Pixeln während einer Pausenperiode zwischen der ersten und der zweiten Bildperiode, wobei diese Pausenperiode eine Länge gleich einem Sub-Vielfachen der Länge einer Bildperiode aufweist.
2. Verfahren nach Anspruch 1, wobei das Verfahren Scannen der Gruppen von Pixeln während mindestens einer ersten, einer zweiten und einer dritten Bildperiode und Unterbrechen des Scannens der Gruppen von Pixeln während mindestens einer ersten und einer zweiten Pausenperiode zwischen aufeinanderfolgenden Bildperioden umfasst.
3. Verfahren nach Anspruch 2, wobei die erste, die zweite und die dritte Bildperiode im Wesentlichen

gleiche Längen aufweisen und die Gesamtlänge der Pausenperioden gleich einer Bildperiode oder einer Bildperiode minus einer Pausenperiode ist.

4. Verfahren nach Anspruch 1, wobei die Pixel in einer Matrix mit mehreren Zeilen und mehreren Spalten angeordnet sind, wobei jedes Pixel durch das Überschneiden einer gegebenen Zeile und einer gegebenen Spalte definiert ist und wobei jede Gruppe von Pixeln eine Zeile oder eine Spalte der Matrix umfasst.
5. Verfahren nach Anspruch 1, wobei die elektrooptische Anzeige ein gekapseltes elektrophoretisches Medium umfasst.
6. Verfahren nach Anspruch 1, wobei die elektrooptische Anzeige ein mikrozellenelektrophoretisches Medium umfasst.

Revendications

1. Procédé d'attaque d'un afficheur électrophorétique à matrice active bistable comportant une pluralité de pixels divisés en une pluralité de groupes, dans lequel une réécriture complète de l'afficheur est effectuée par un procédé de modulation d'impulsion en largeur en balayant la matrice une pluralité de fois au cours de périodes de trame de mêmes longueurs, en délivrant chaque fois à chaque pixel soit une tension d'attaque soit une tension de non-attaque, le procédé consistant à :
 - (a) balayer la matrice en sélectionnant chacun de la pluralité de groupes de pixels et en appliquant à chacun des pixels du groupe sélectionné soit la tension d'attaque soit la tension de non-attaque, le balayage de tous les groupes de pixels étant effectué au cours d'une première desdites périodes de trame ; et
 - (b) répéter le balayage des groupes de pixels au cours d'une deuxième desdites périodes de trame,
 le procédé étant **caractérisé en ce que** le balayage des groupes de pixels est interrompu au cours d'une période de pause entre les première et deuxième périodes de trame, ladite période de pause ayant une longueur égale à un sous-multiple d'une période de trame.
2. Procédé selon la revendication 1, dans lequel le procédé consiste à balayer les groupes de pixels au cours d'au moins des première, deuxième et troisième périodes de trame, et à interrompre le balayage des groupes de pixels au cours d'au moins des première et deuxième périodes de pause entre des pé-

riodes de trame successives.

3. Procédé selon la revendication 2, dans lequel les première, deuxième et troisième périodes de trame ont sensiblement les mêmes longueurs et la longueur totale des périodes de pause est égale à une période de trame ou à une période de trame moins une période de pause. 5
4. Procédé selon la revendication 1, dans lequel les pixels sont agencés en une matrice ayant une pluralité de lignes et une pluralité de colonnes, chaque pixel étant défini par l'intersection d'une ligne donnée et d'une colonne donnée, et dans lequel chaque groupe de pixels comprend une ligne ou une colonne de la matrice. 10 15
5. Procédé selon la revendication 1, dans lequel l'afficheur électro-optique comprend un support électrophorétique encapsulé. 20
6. Procédé selon la revendication 1, dans lequel l'afficheur électro-optique comprend un support électrophorétique à microcellules. 25

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