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(54) **LOCAL DIMMING FOR PANEL DISPLAY DEVICES USING TWO-DIMENSIONAL LIGHT SOURCE ARRAY**

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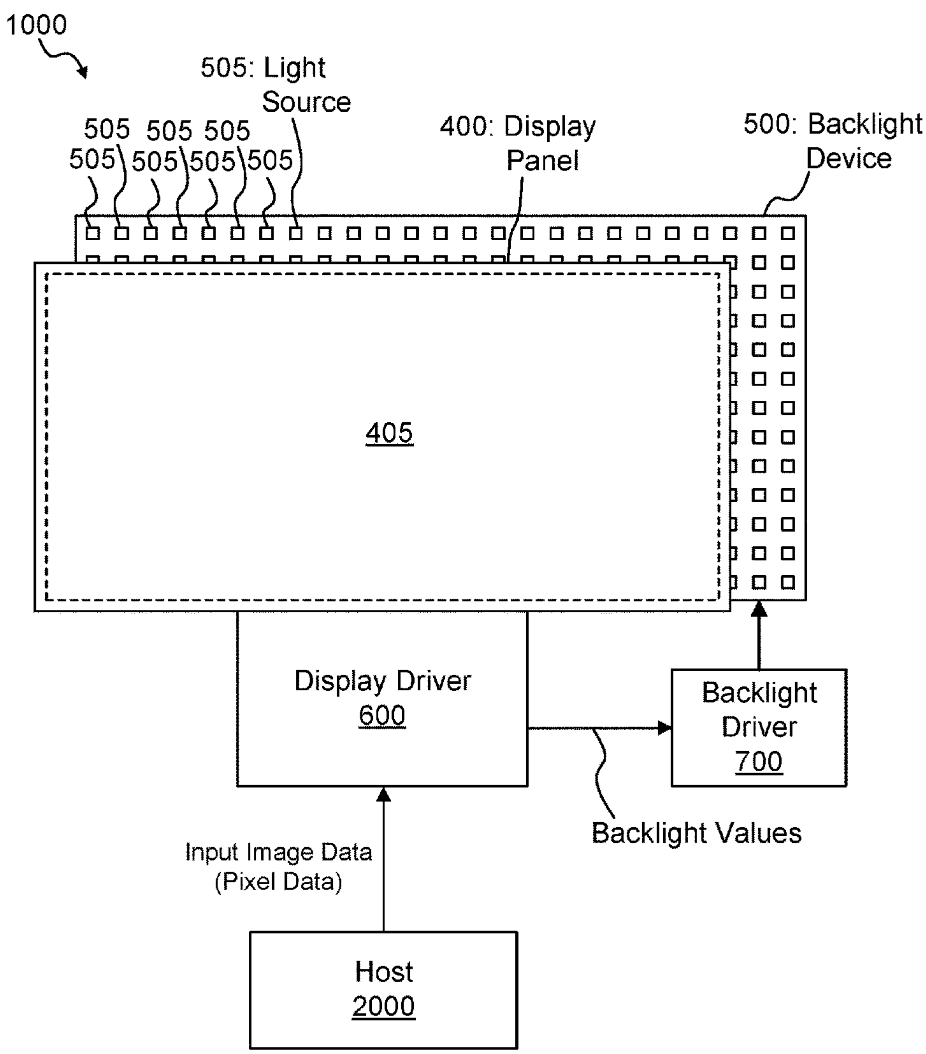
(57) **ABSTRACT**

A display device includes a backlight device, a driver circuit, and a backlight control circuit. The backlight device includes an array of light sources configured to illuminate a display area of a display panel. The display area is segmented into zones corresponding to the light sources, respectively. The zones include inner zones and outmost zones. The inner light sources of the light source array are each located at a center of corresponding one of the inner zones. Each outmost zone is different in shape from at least one inner zone which is adjacent to at least one outmost zone. The backlight control circuit is configured to control a luminance level of a first outmost light source of the array of light sources based on pixel data of pixels in a first outmost zone of the outmost zones, and the first outmost light source corresponds to the first outmost zone.



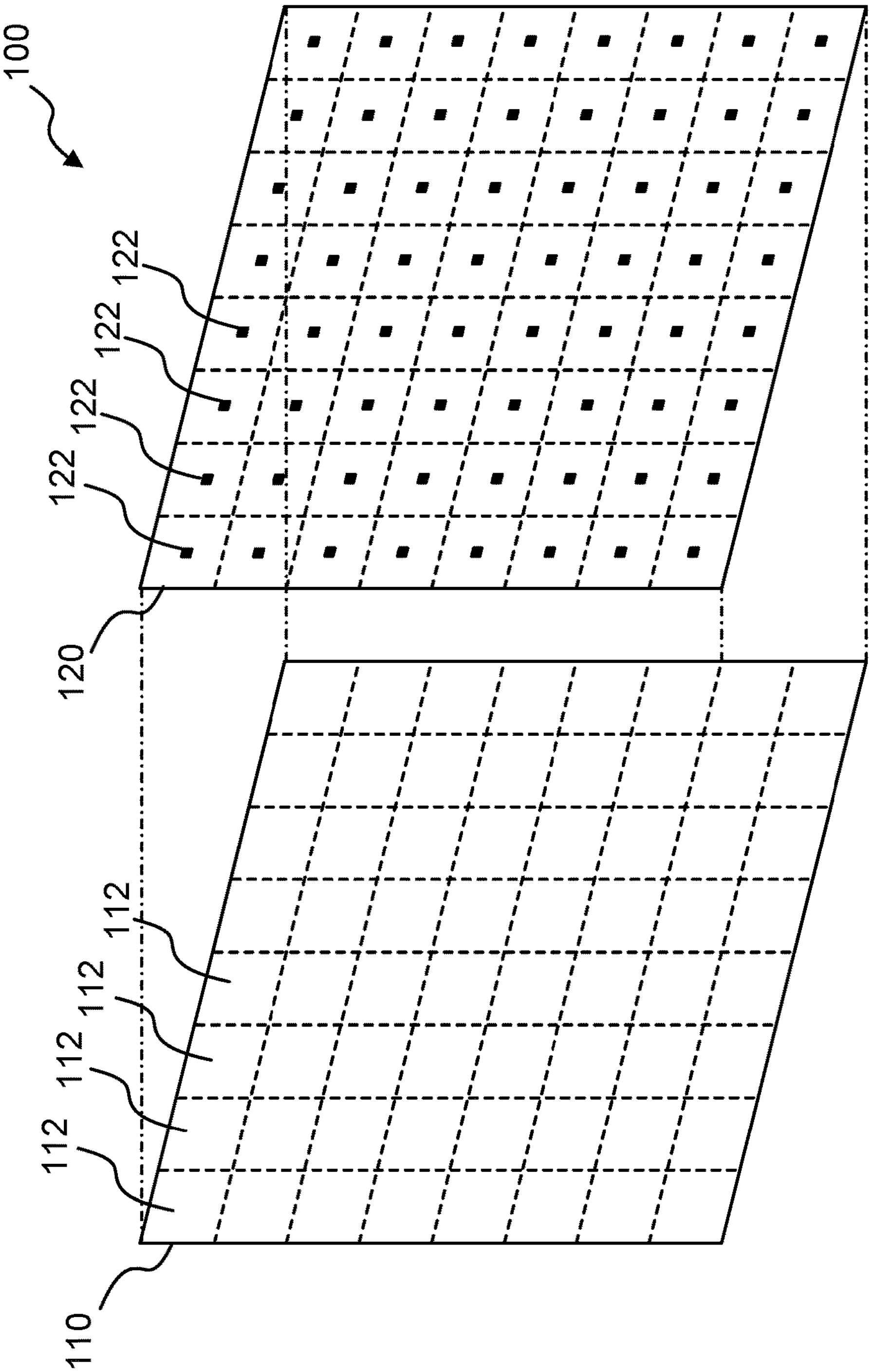
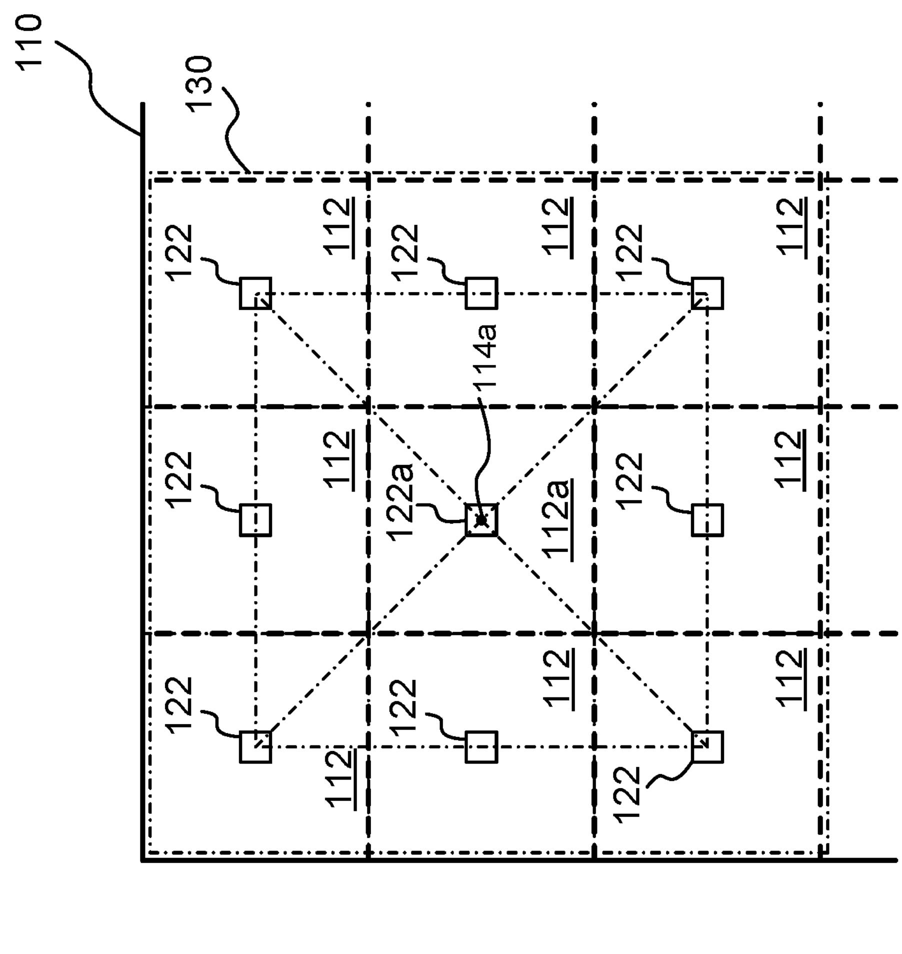


FIG. 1A

FIG. 1B



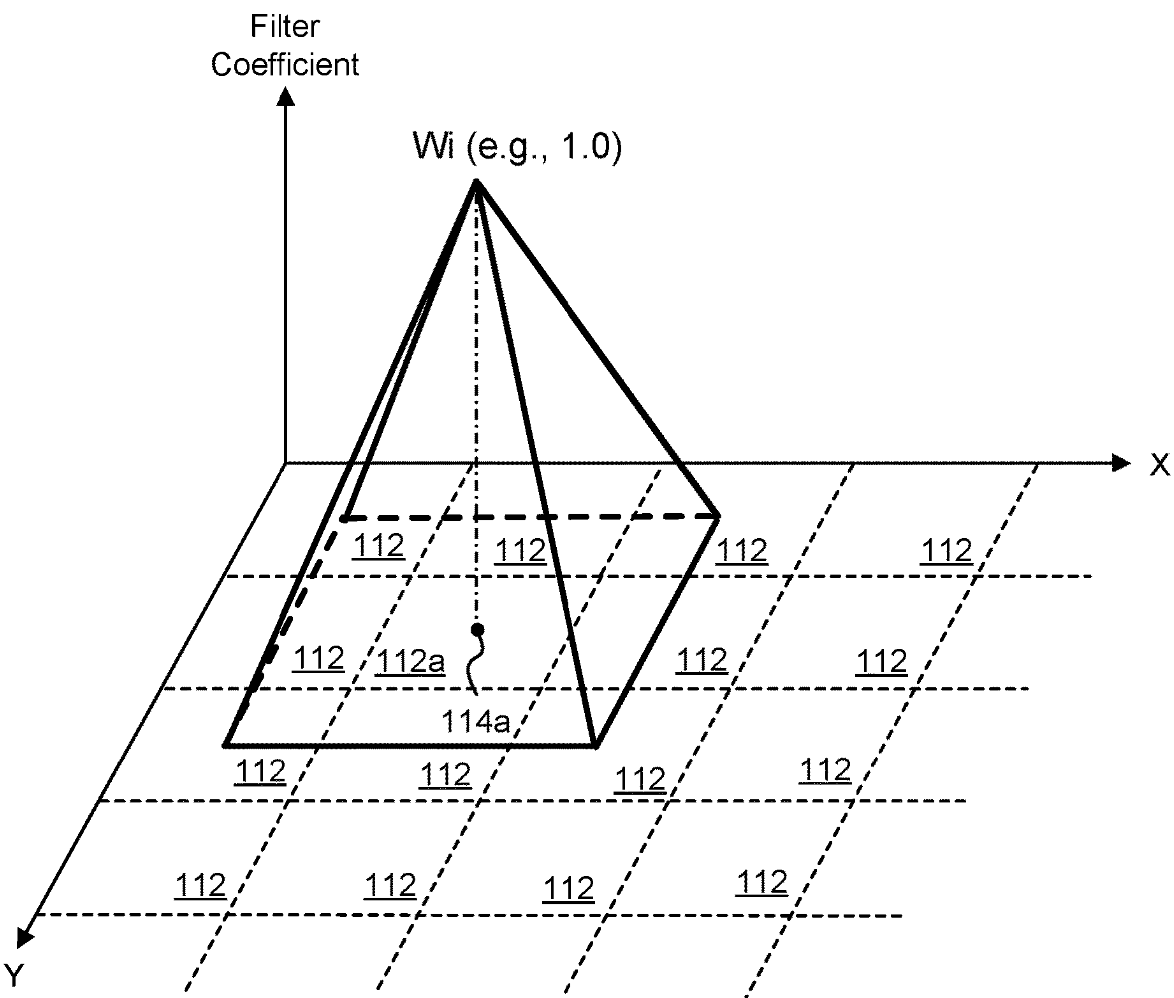

Filter Coefficient
Wi (e.g., 1.0)
X
Y
112
112
112
112
112
112a
112
112
114a
112
112
112
112
112
112
112
112

FIG. 2

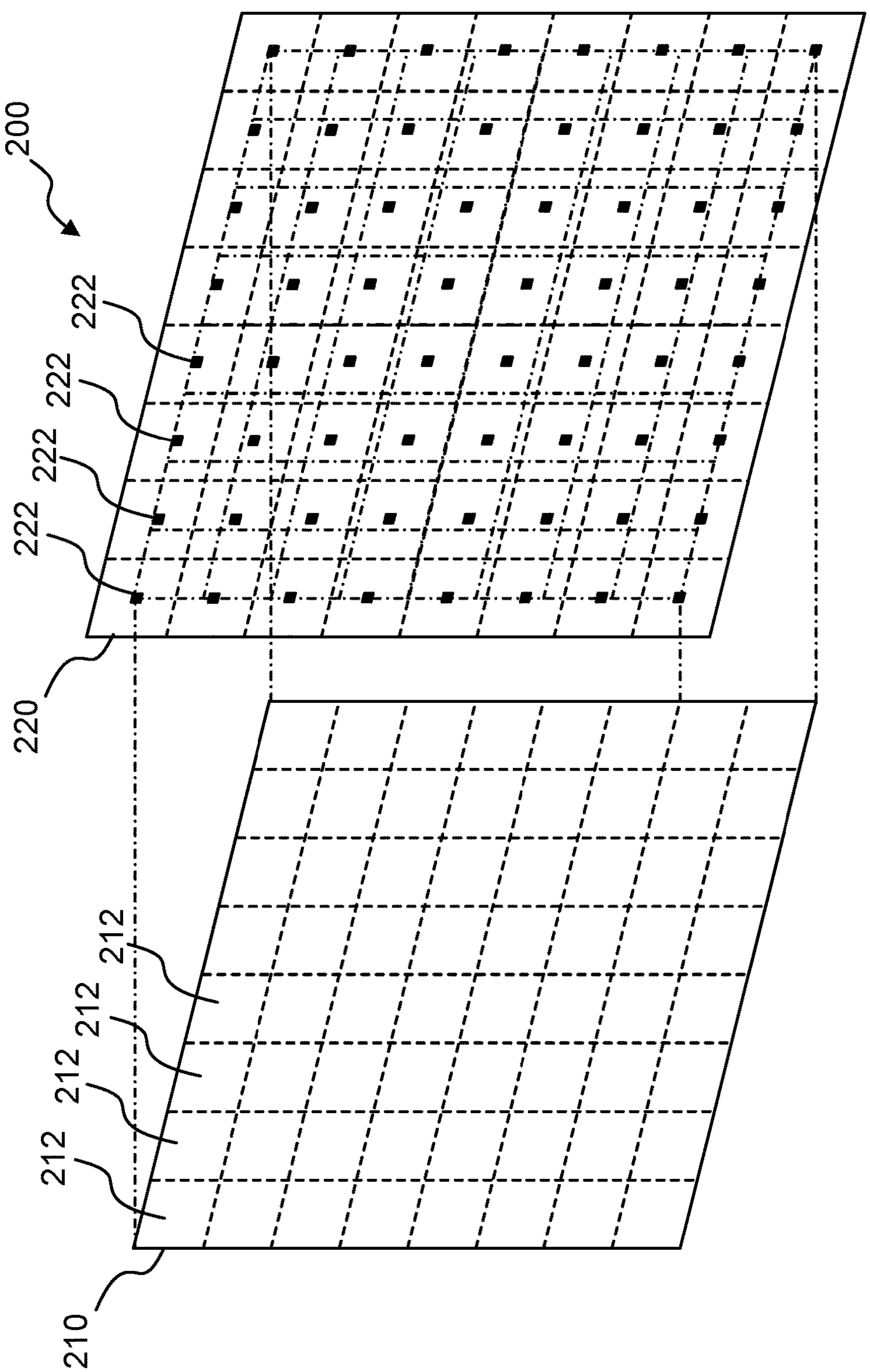


FIG. 3A

FIG. 3B

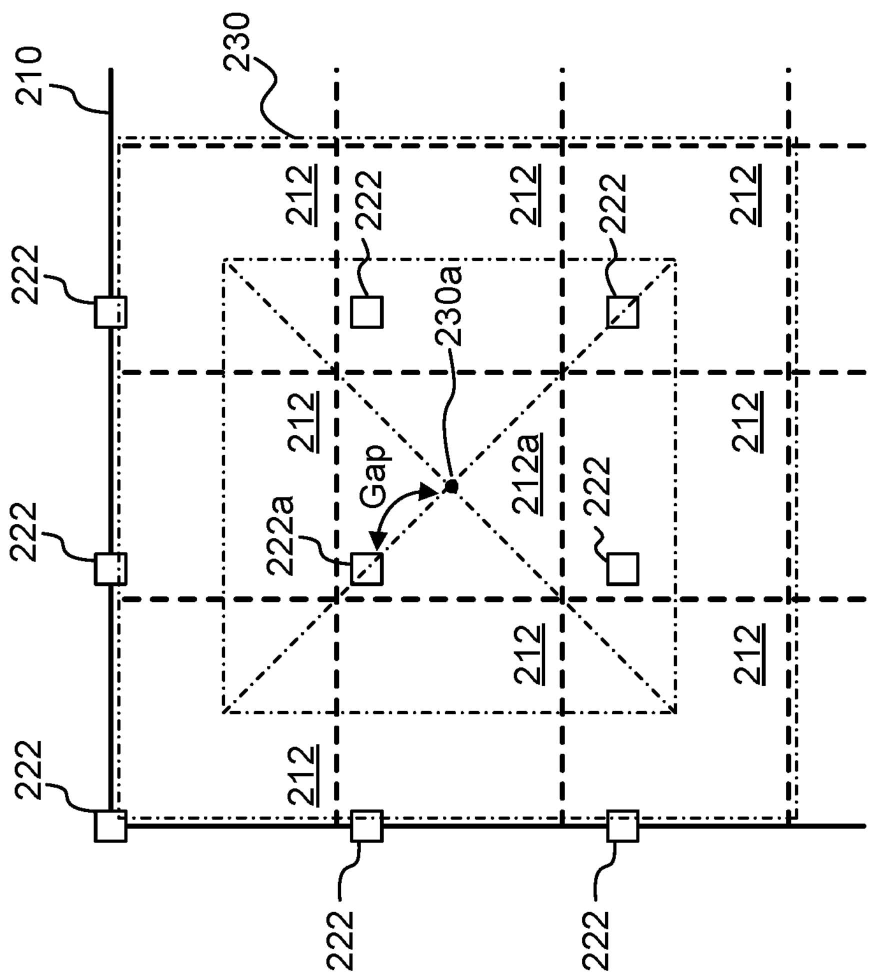


FIG. 4A

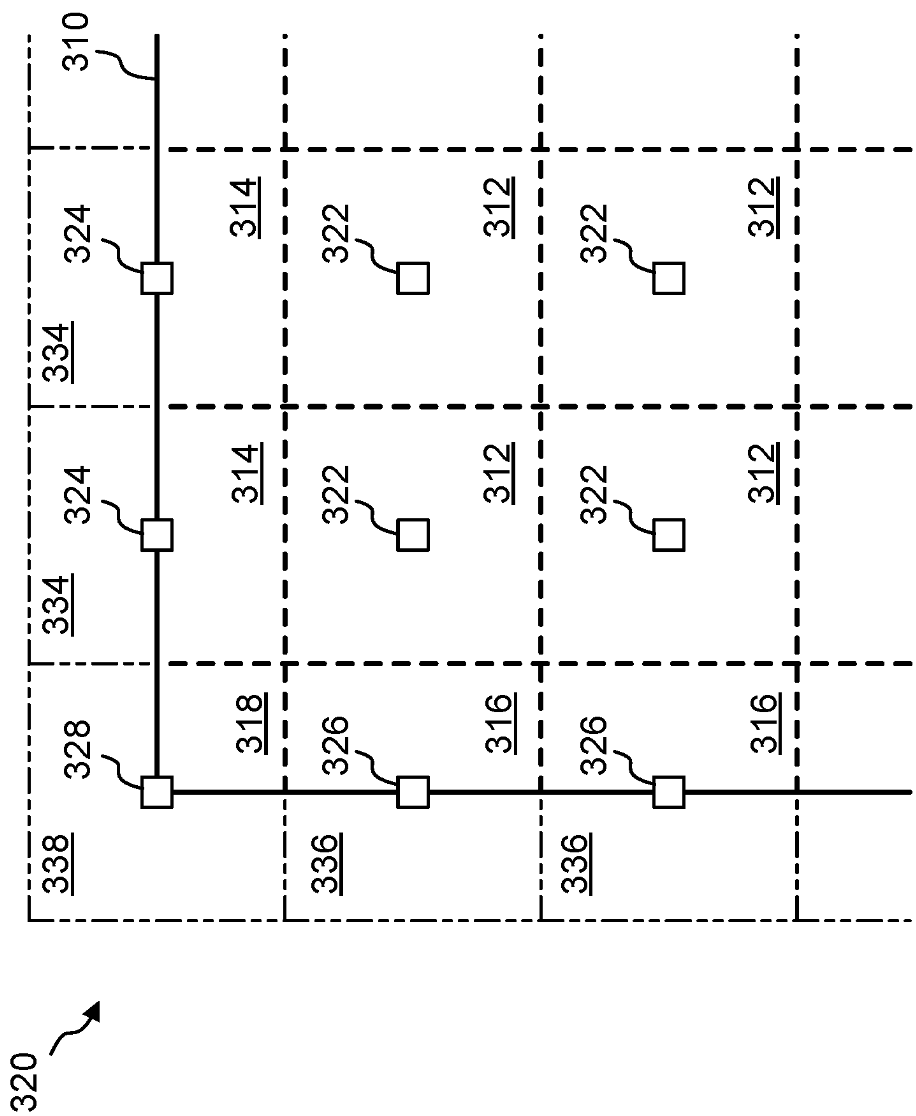
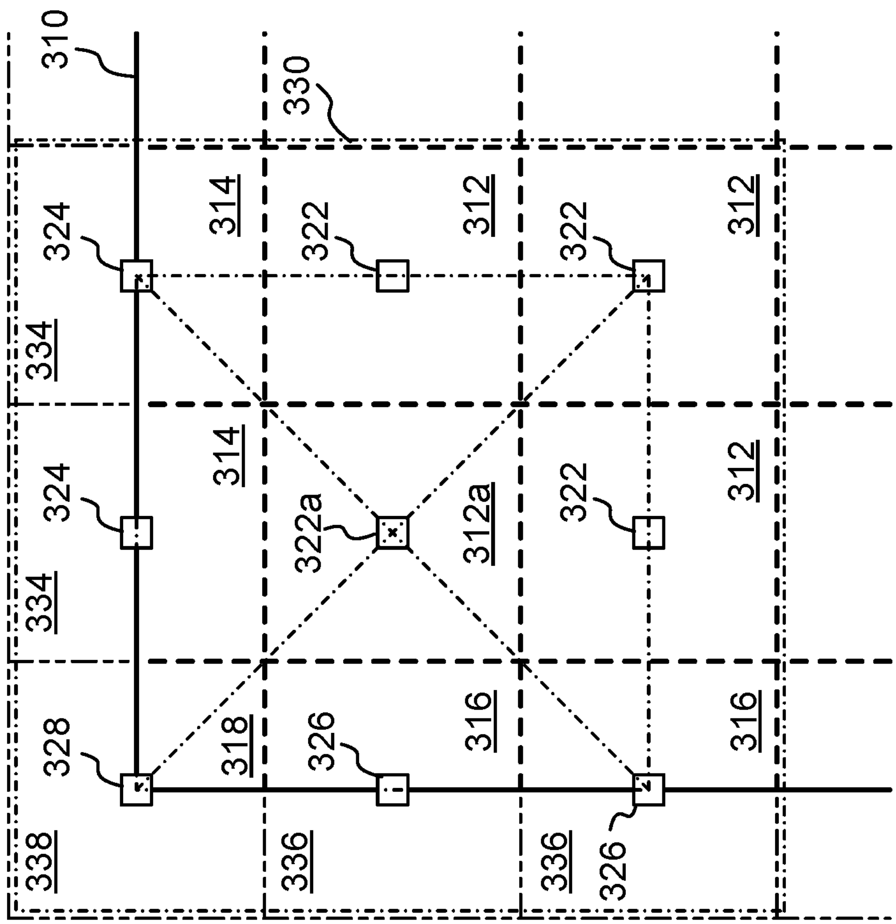

310
324
324
328
334
334
338
314
314
318
322
322
326
336
312
312
316
322
322
326
336
312
312
316
320

FIG. 4B


310
330
324
324
328
314
314
318
322
322
322
322a
326
326
312
312
312
312a
316
316
334
334
338
336
336

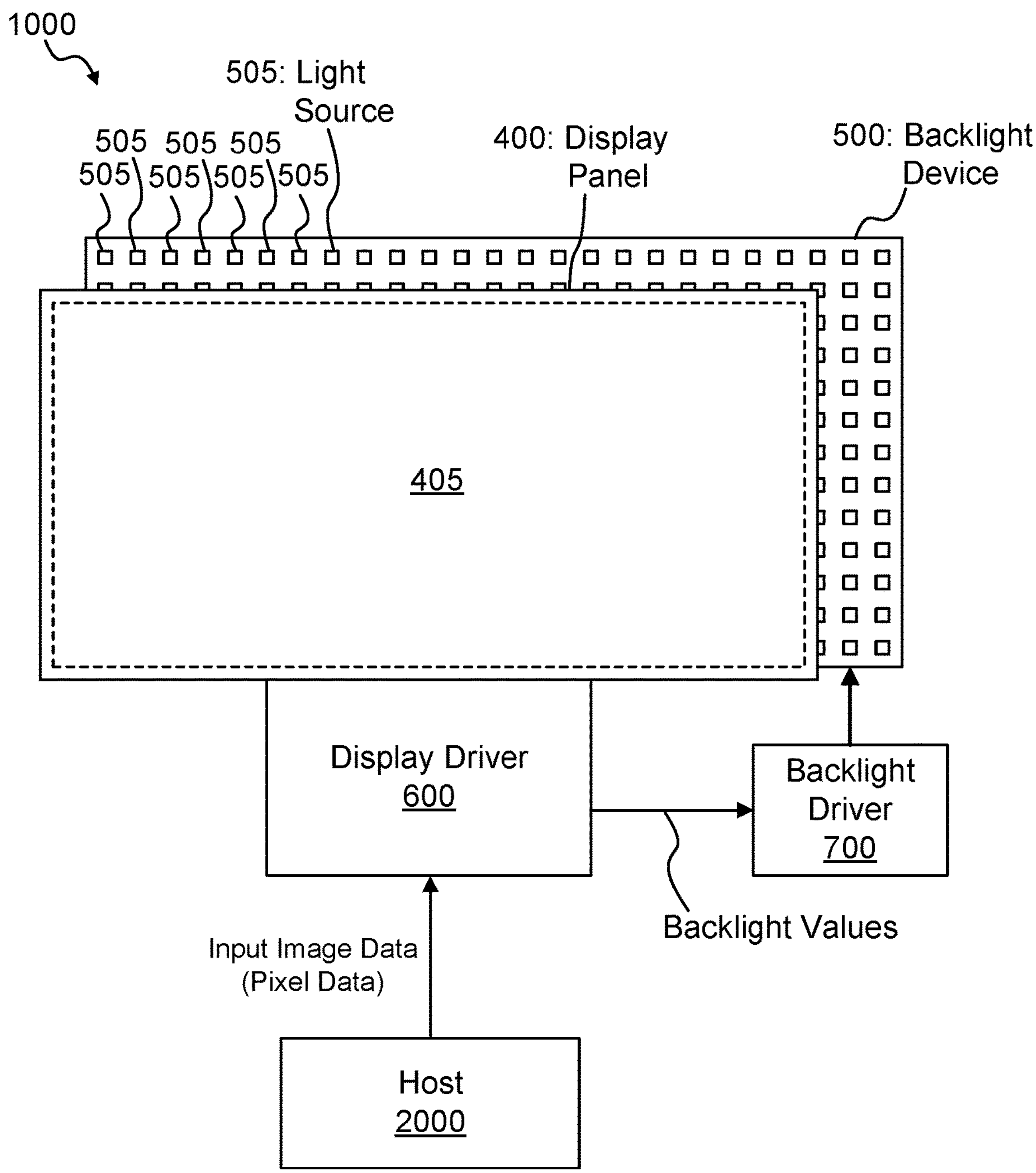

1000
505: Light Source
505 505 505
505 505 505 505
400: Display Panel
500: Backlight Device
405
Display Driver
600
Backlight Driver
700
Backlight Values
Input Image Data
(Pixel Data)
Host
2000

FIG. 5

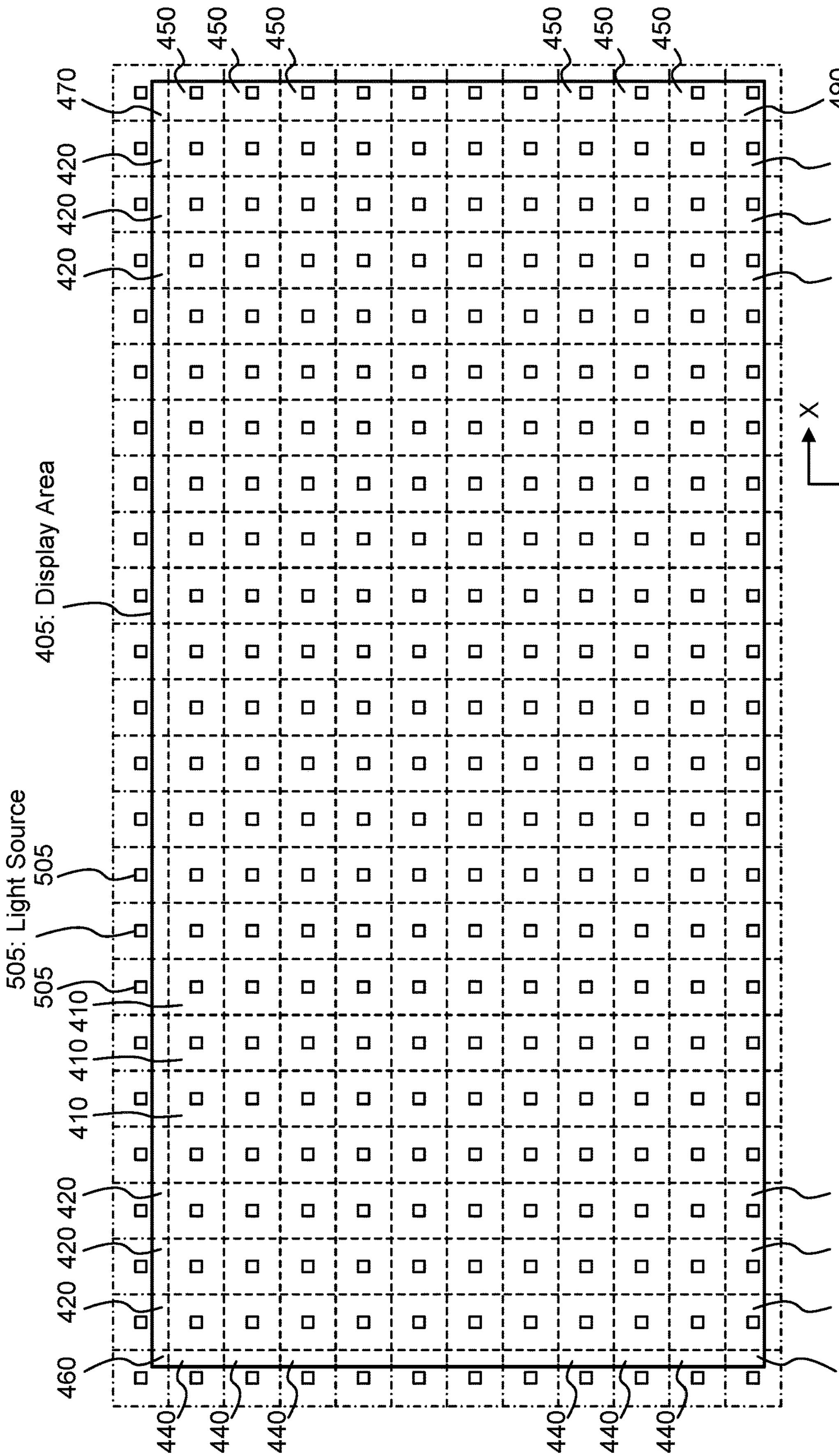

405: Display Area
505: Light Source
505
505
410
410
410
420
420
420
420
420
420
430
430
430
430
430
430
440
440
440
440
440
440
450
450
450
450
450
450
460
470
480
490
X
Y

FIG. 6

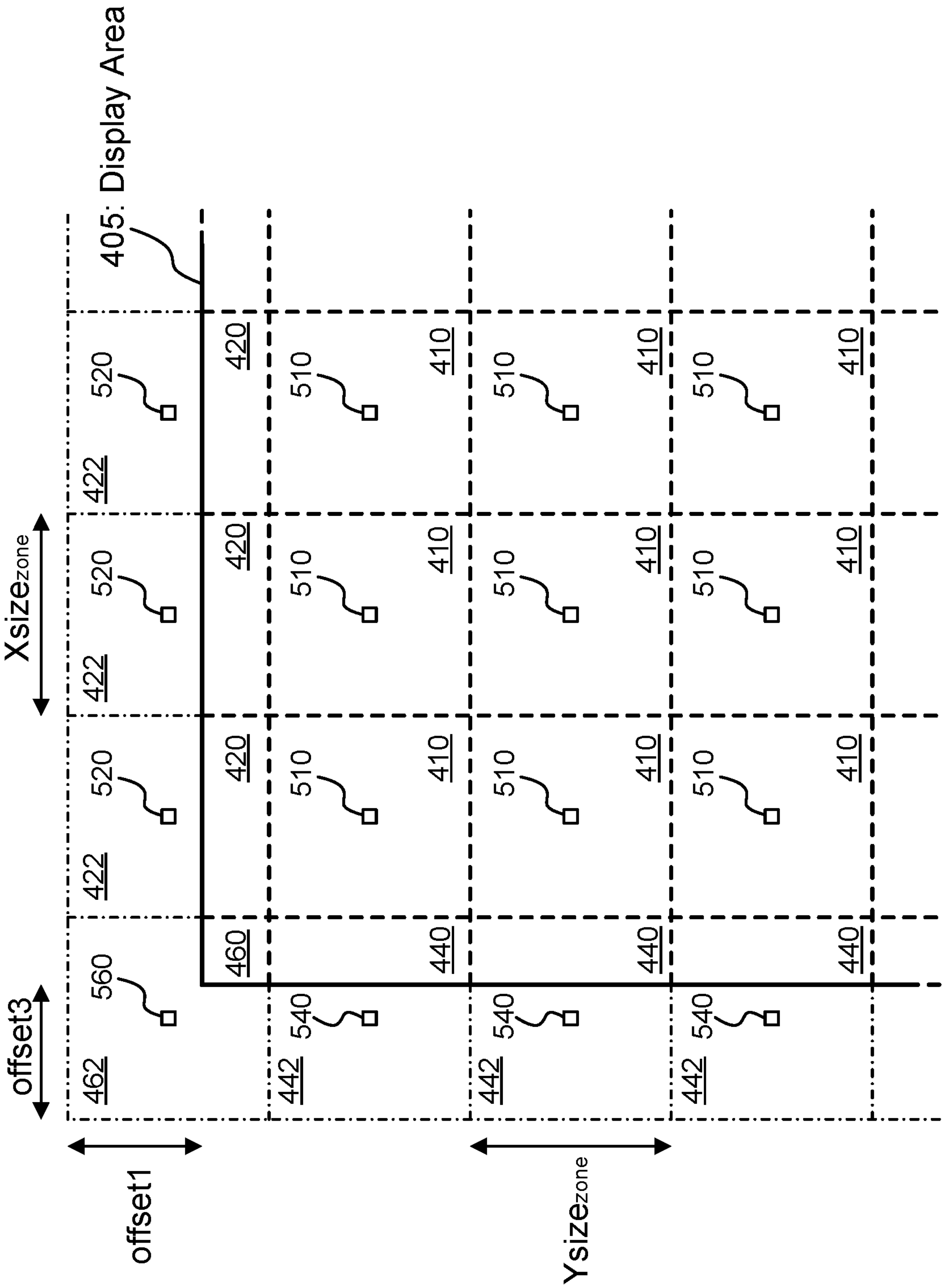

405: Display Area
Xsize_zone
offset3
offset1
Ysize_zone
422
520
420
510
410
462
560
460
442
540
440

FIG. 7A

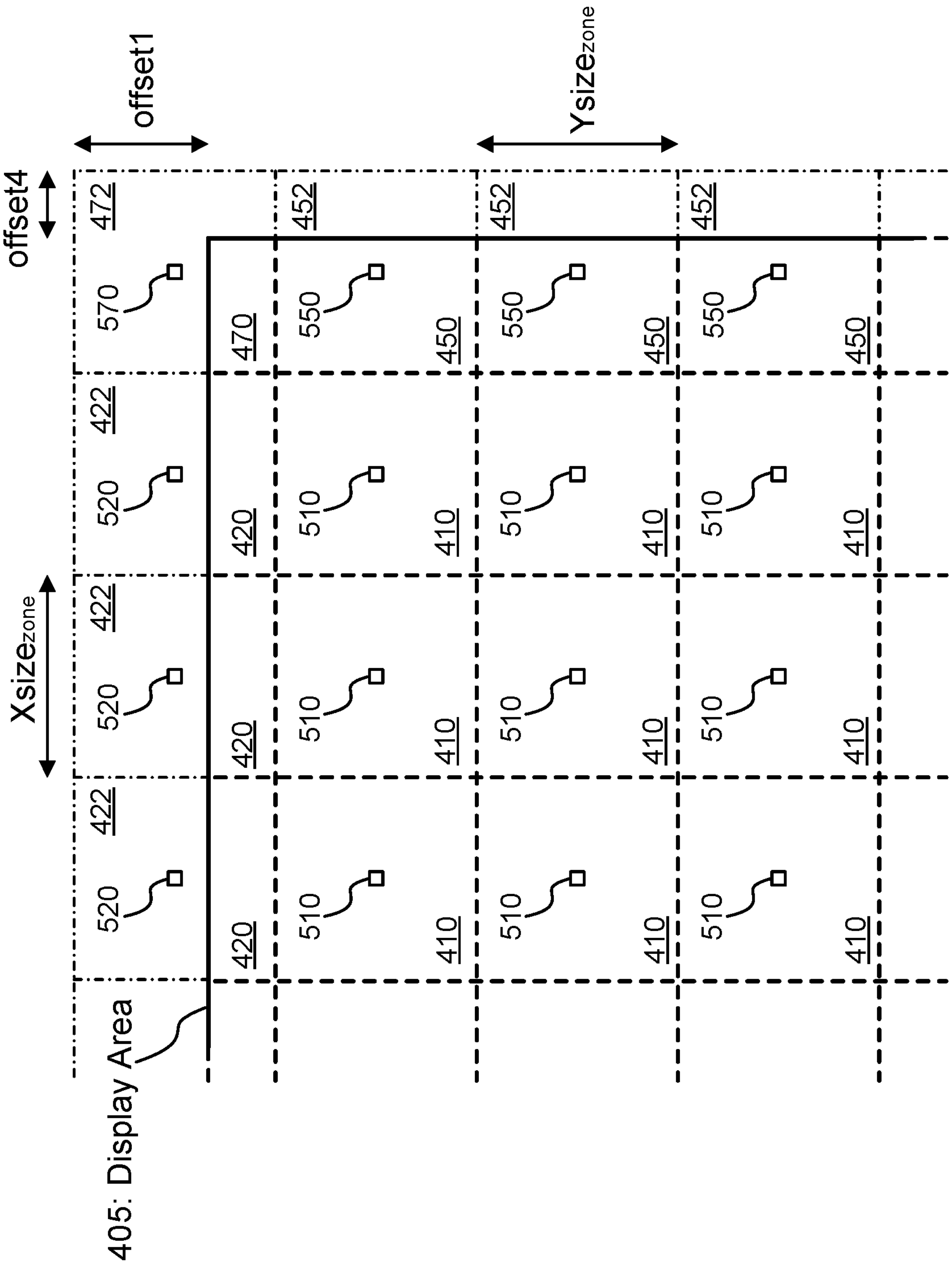

offset1
Ysizezone
offset4
Xsizezone
405: Display Area
472
452
570
550
470
450
422
520
510
420
410

FIG. 7B

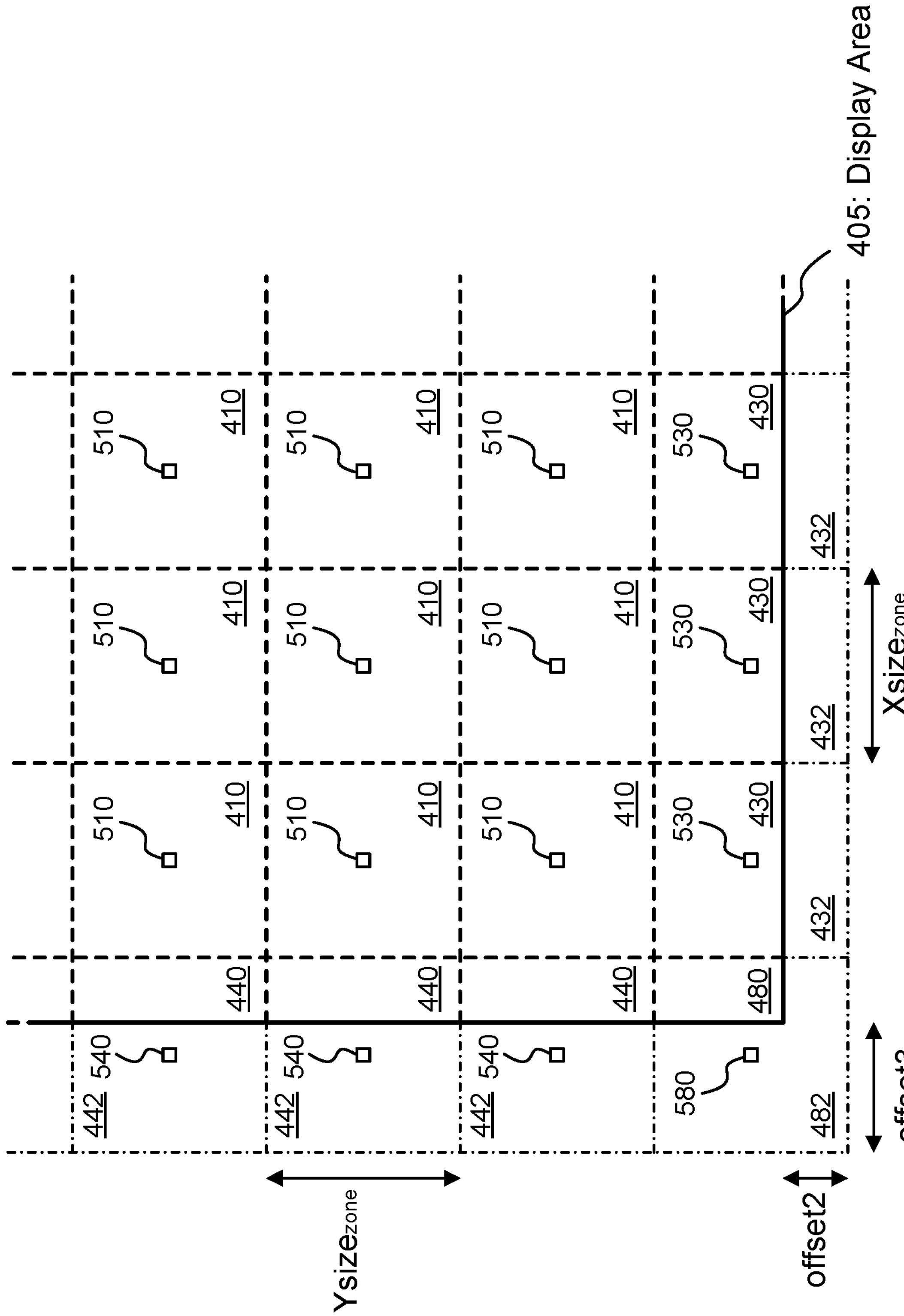
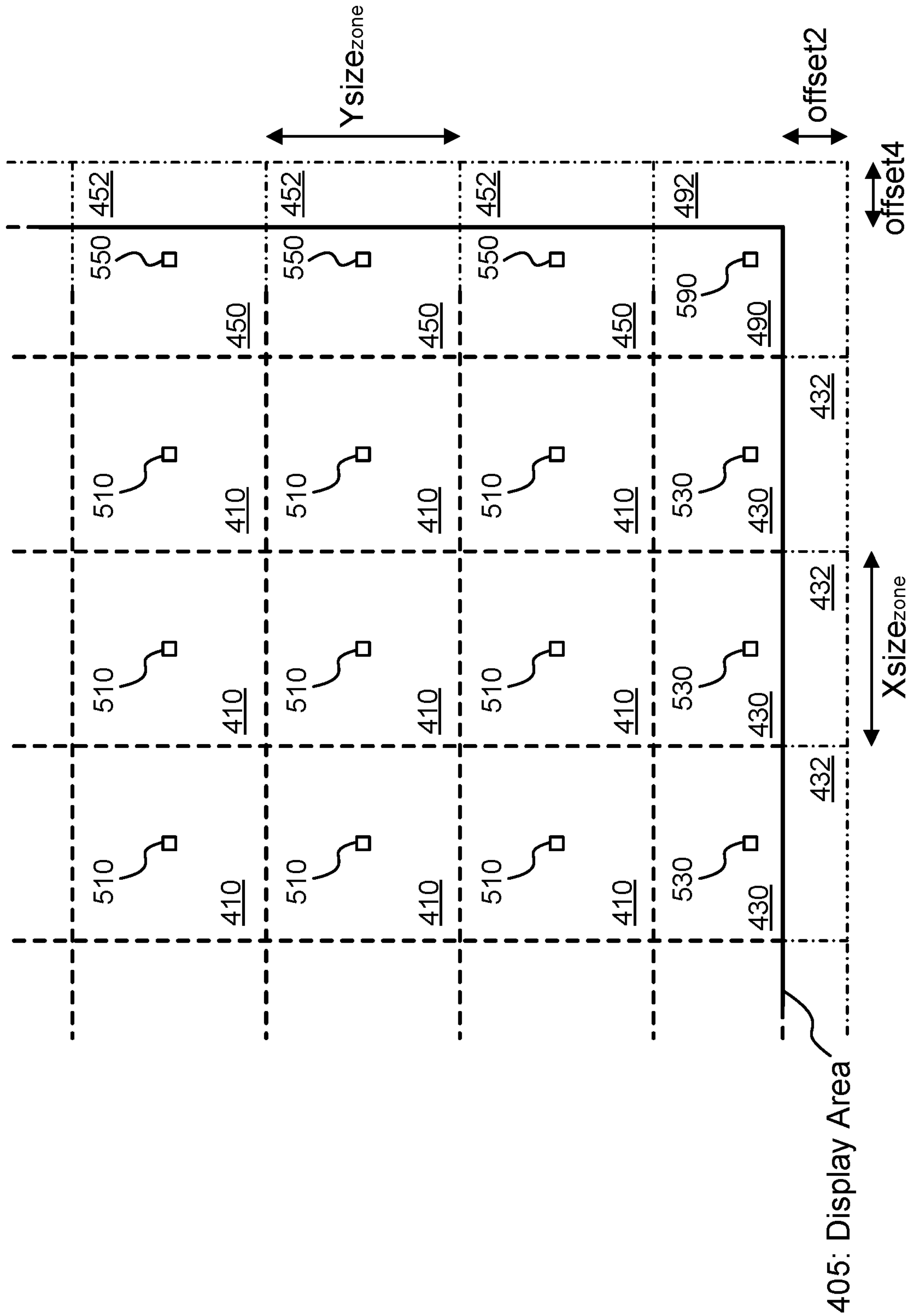

405: Display Area
410
430
432
440
442
480
482
510
530
540
580
Xsize$_{zone}$
Ysize$_{zone}$
offset2
offset3

FIG. 7C



Ysizezone
offset2
offset4
452
452
452
492
550
550
550
590
450
450
450
490
510
410
530
430
432
Xsizezone
405: Display Area

FIG. 7D

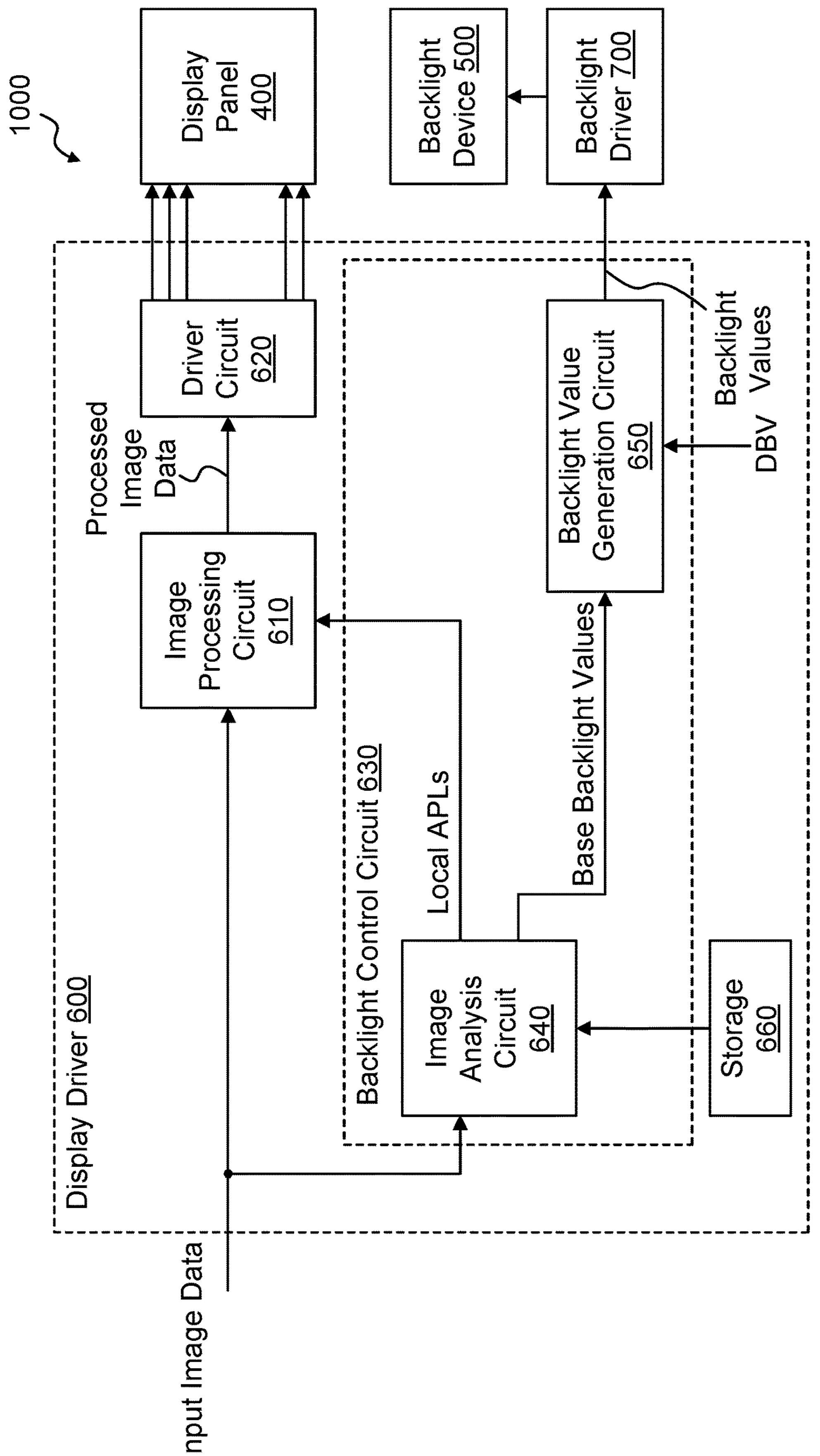

1000
Display Driver 600
Input Image Data
Image Processing Circuit 610
Processed Image Data
Driver Circuit 620
Display Panel 400
Backlight Control Circuit 630
Image Analysis Circuit 640
Local APLs
Base Backlight Values
Backlight Value Generation Circuit 650
DBV
Backlight Values
Storage 660
Backlight Device 500
Backlight Driver 700

FIG. 8

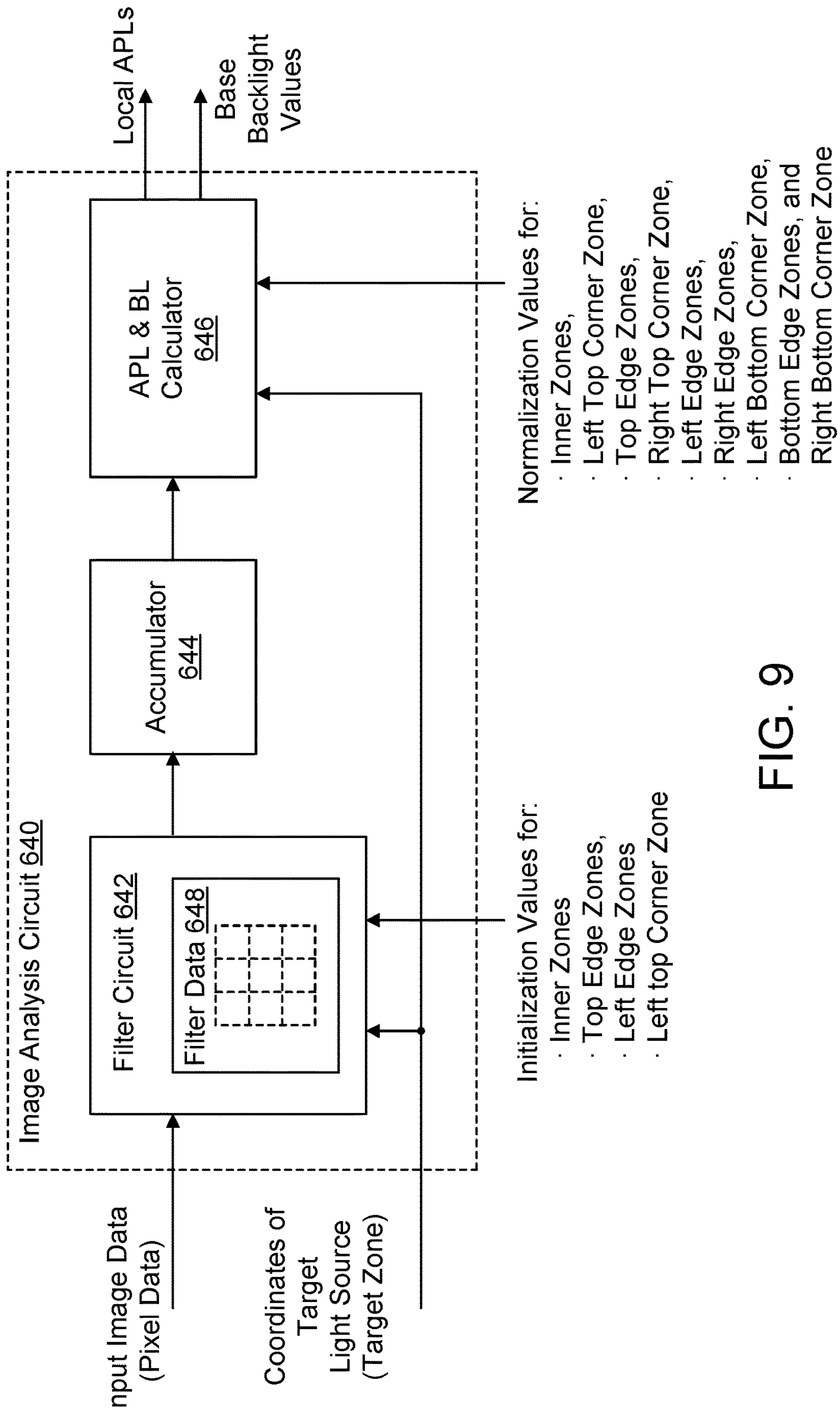

Input Image Data (Pixel Data)
Coordinates of Target Light Source (Target Zone)
Image Analysis Circuit 640
Filter Circuit 642
Filter Data 648
Accumulator 644
APL & BL Calculator 646
Local APLs
Base Backlight Values
Initialization Values for:
· Inner Zones
· Top Edge Zones,
· Left Edge Zones
· Left top Corner Zone
Normalization Values for:
· Inner Zones,
· Left Top Corner Zone,
· Top Edge Zones,
· Right Top Corner Zone,
· Left Edge Zones,
· Right Edge Zones,
· Left Bottom Corner Zone,
· Bottom Edge Zones, and
· Right Bottom Corner Zone

FIG. 9

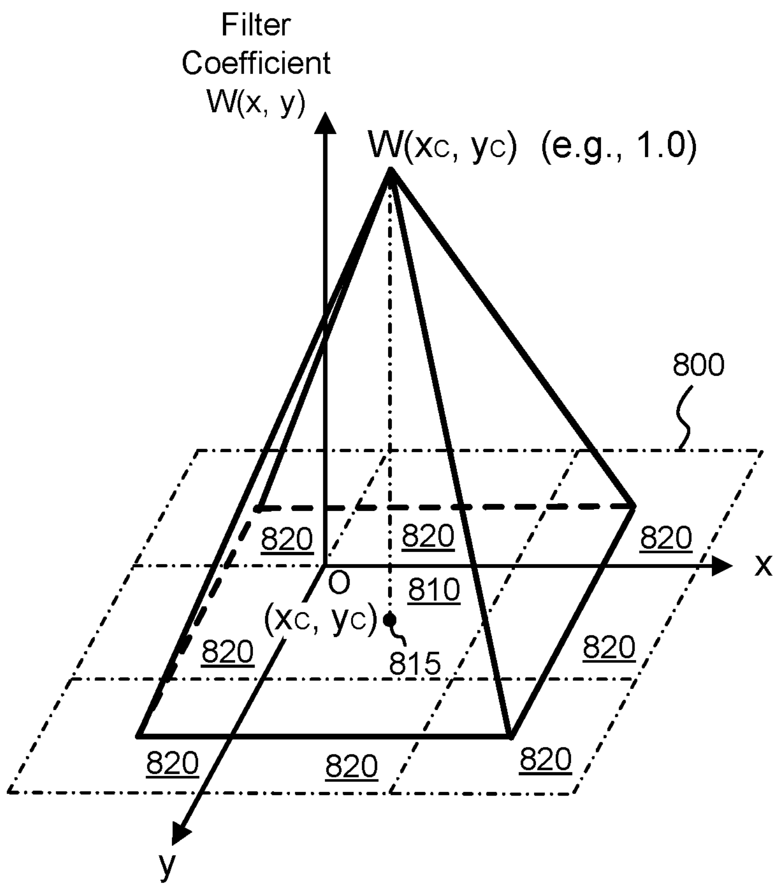

Filter
Coefficient
W(x, y)
W(xC, yC) (e.g., 1.0)
800
820
820
820
x
O
810
(xC, yC)
815
820
820
820
820
820
y

FIG. 10

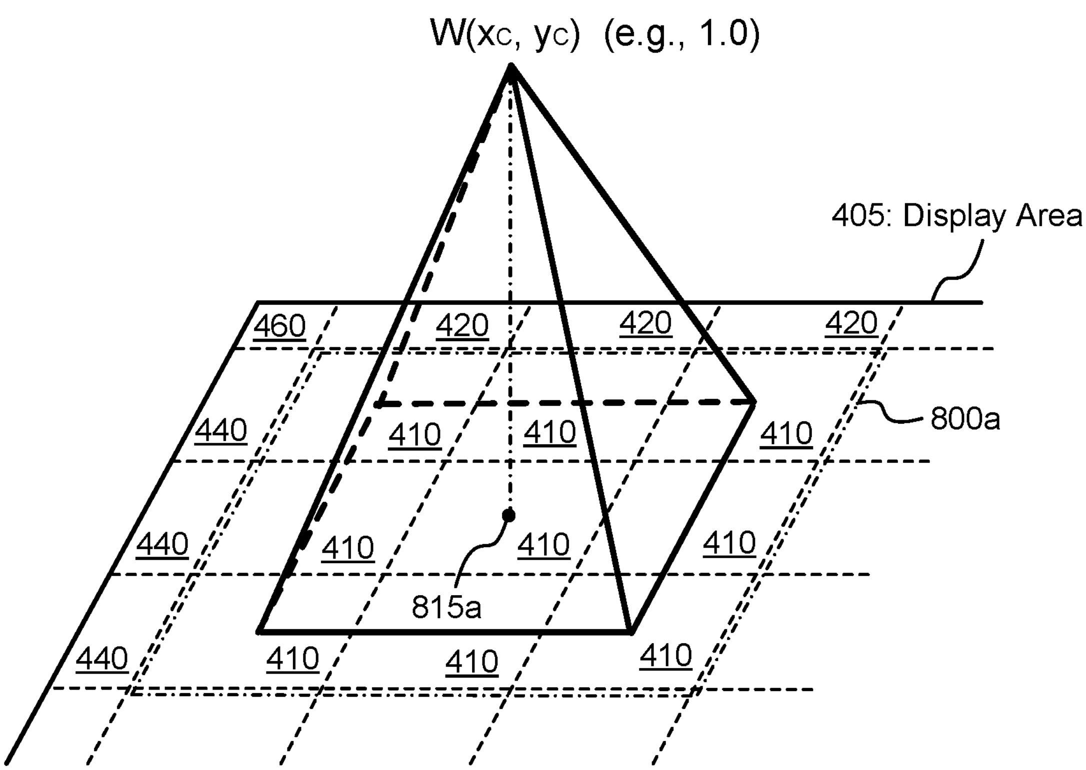

W(xc, yc) (e.g., 1.0)
405: Display Area
460
420
420
420
440
410
410
410
800a
440
410
410
410
815a
440
410
410
410

FIG. 11A

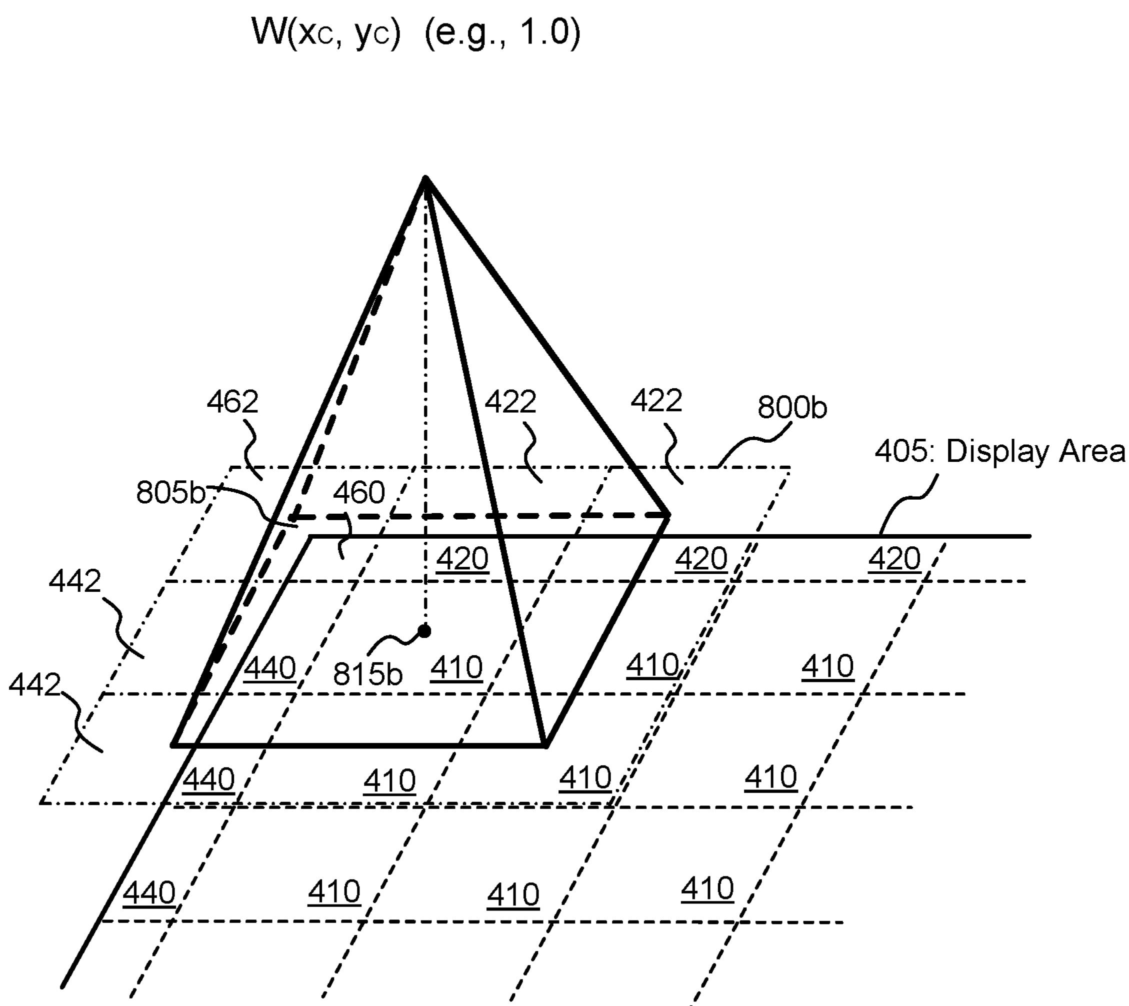

W(xc, yc) (e.g., 1.0)
462
422
422
800b
405: Display Area
805b
460
420
420
420
442
442
440
815b
410
410
410
440
410
410
410
440
410
410
410

FIG. 11B

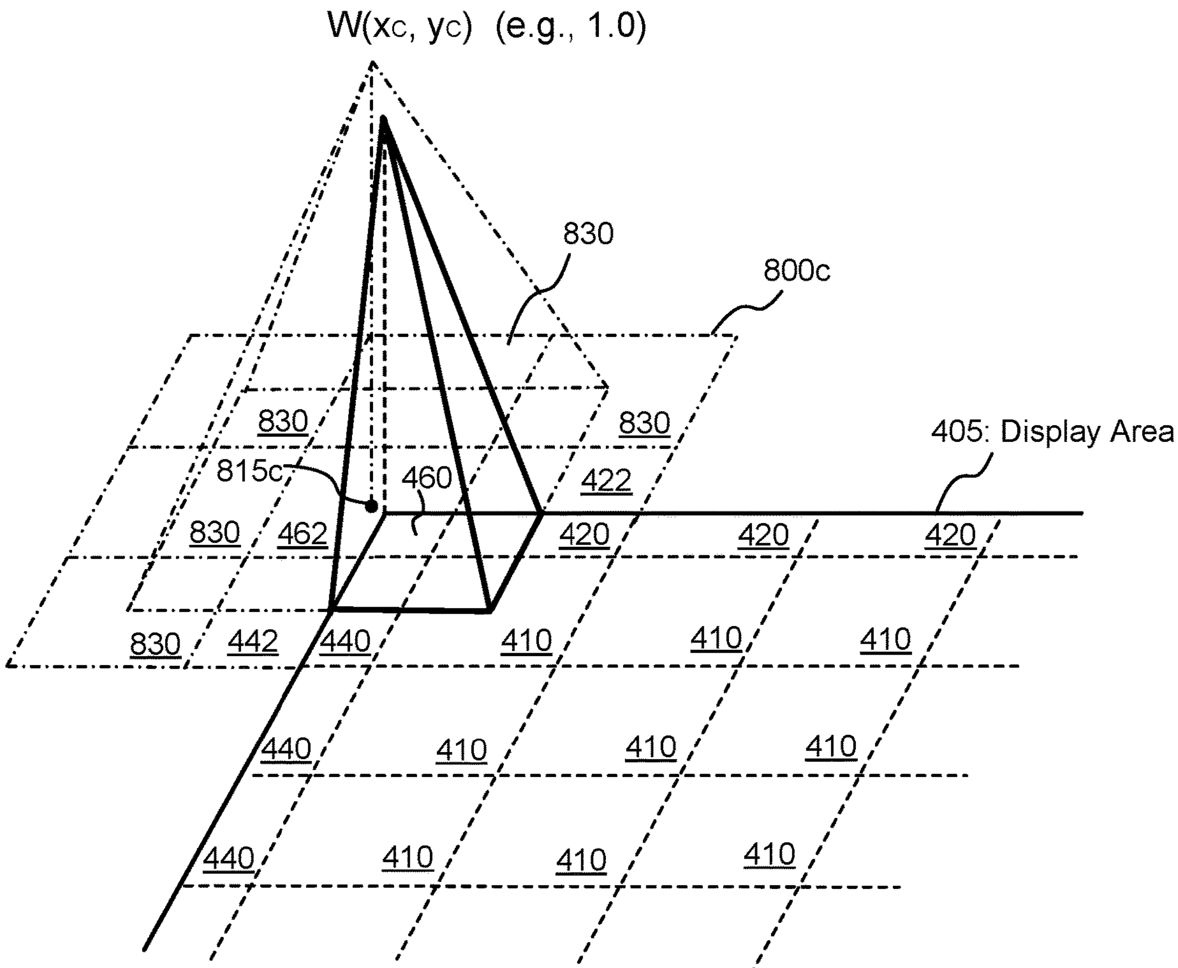

W(xc, yc) (e.g., 1.0)
830
800c
830
830
405: Display Area
815c
460
422
830
462
420
420
420
830
442
440
410
410
410
440
410
410
410
440
410
410
410

FIG. 11C

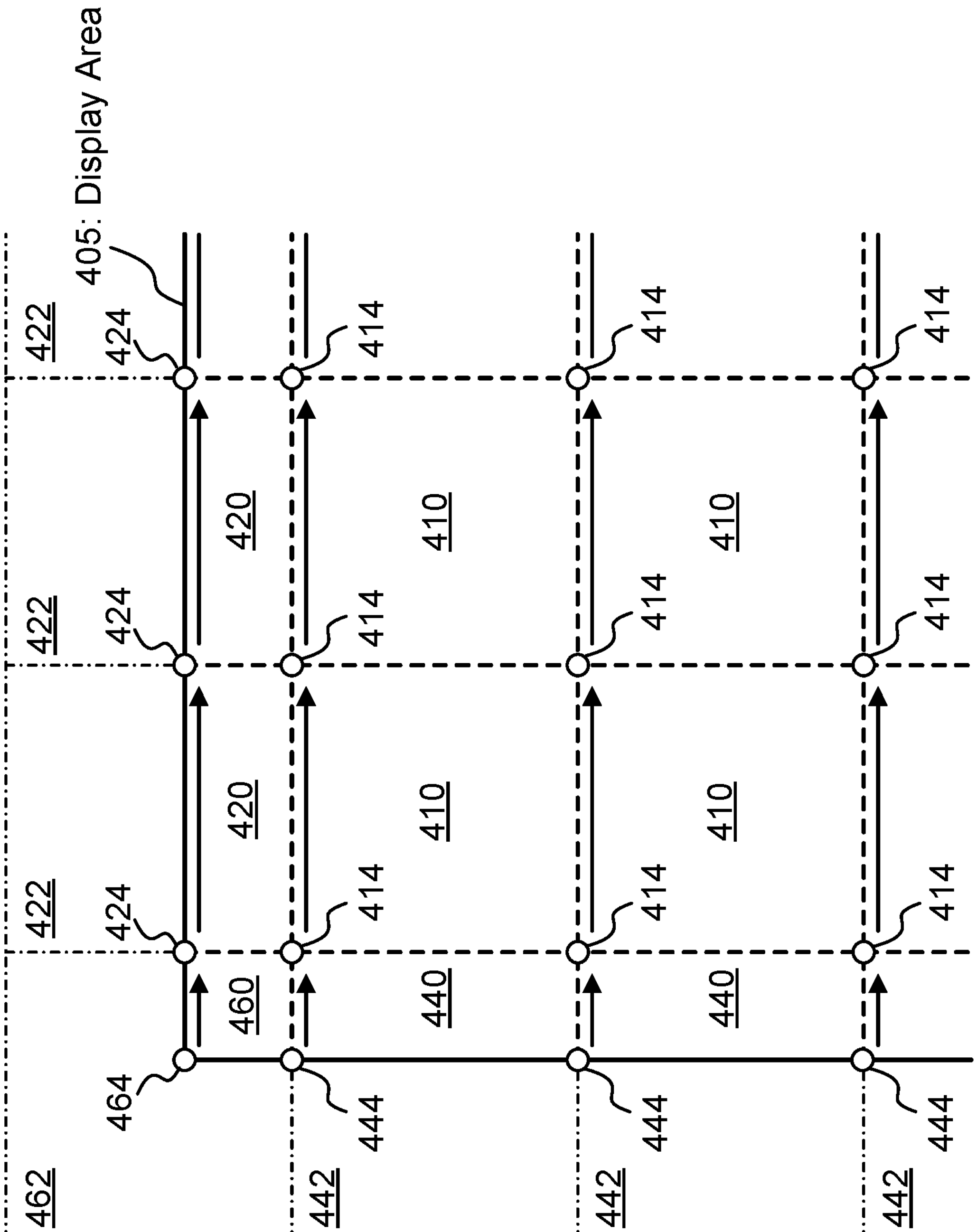


FIG. 12A

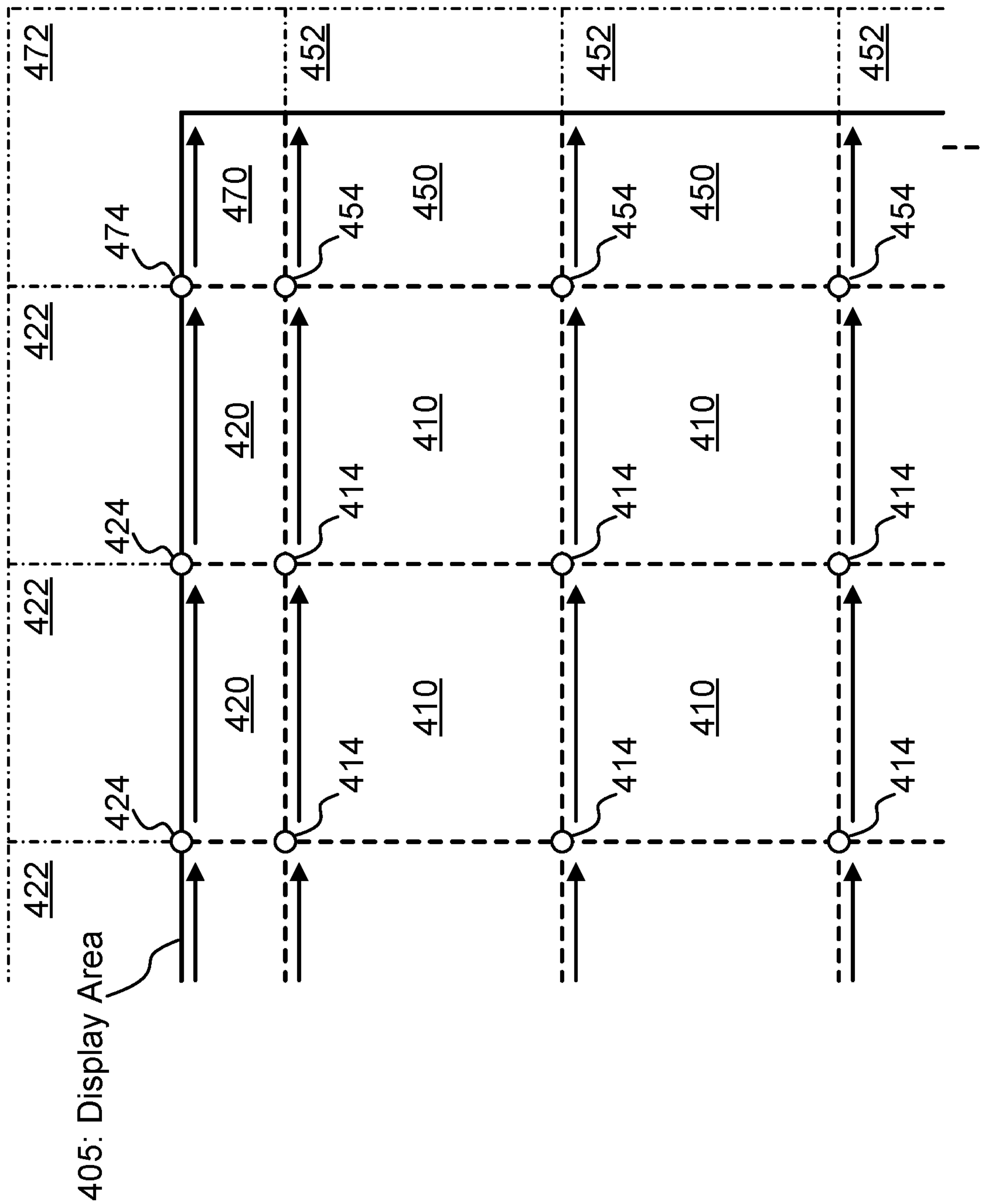

472
452
452
452
474
470
454
450
454
450
454
422
420
410
410
424
414
414
414
422
420
410
410
424
414
414
414
422
405: Display Area

FIG. 12B

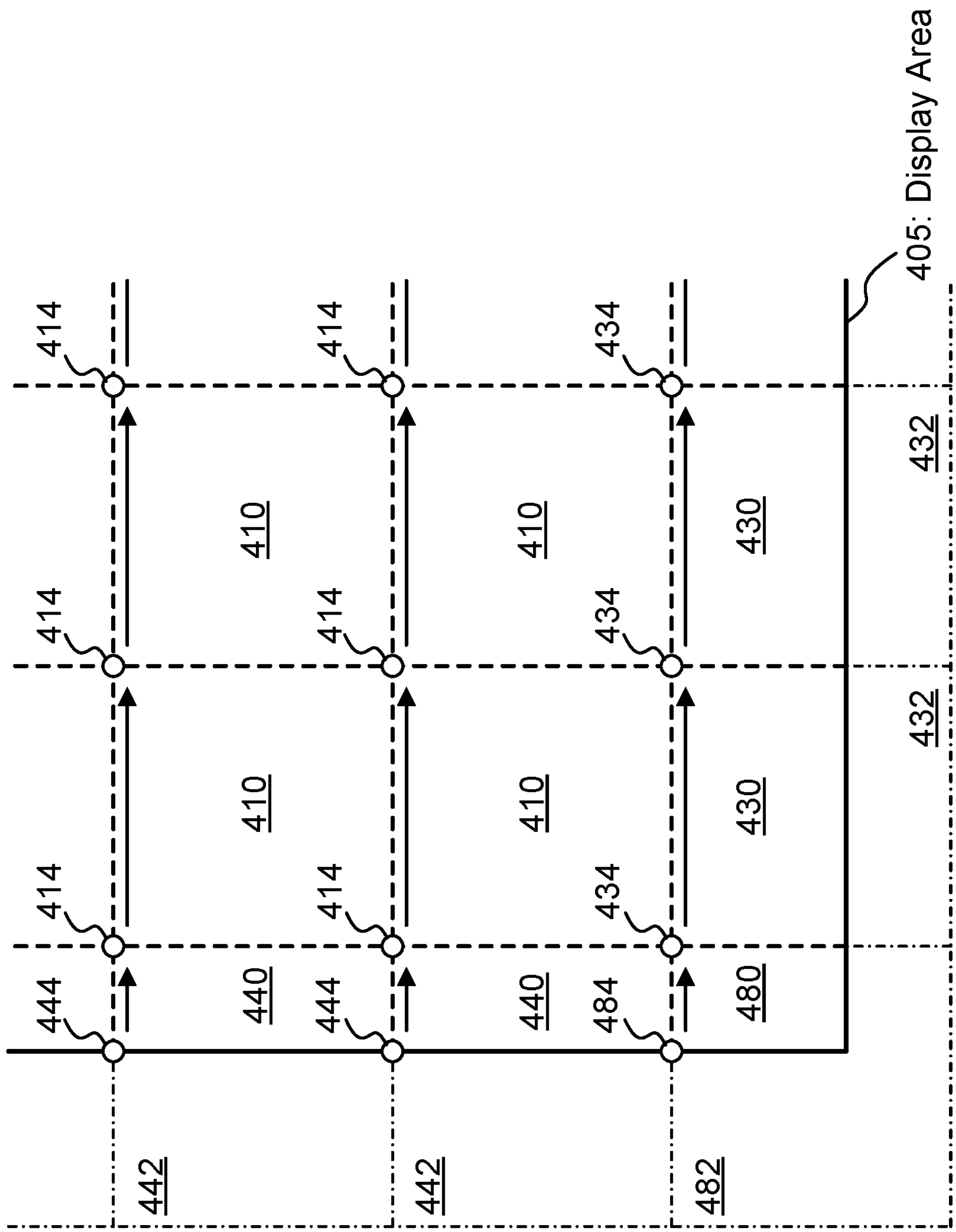


FIG. 12C

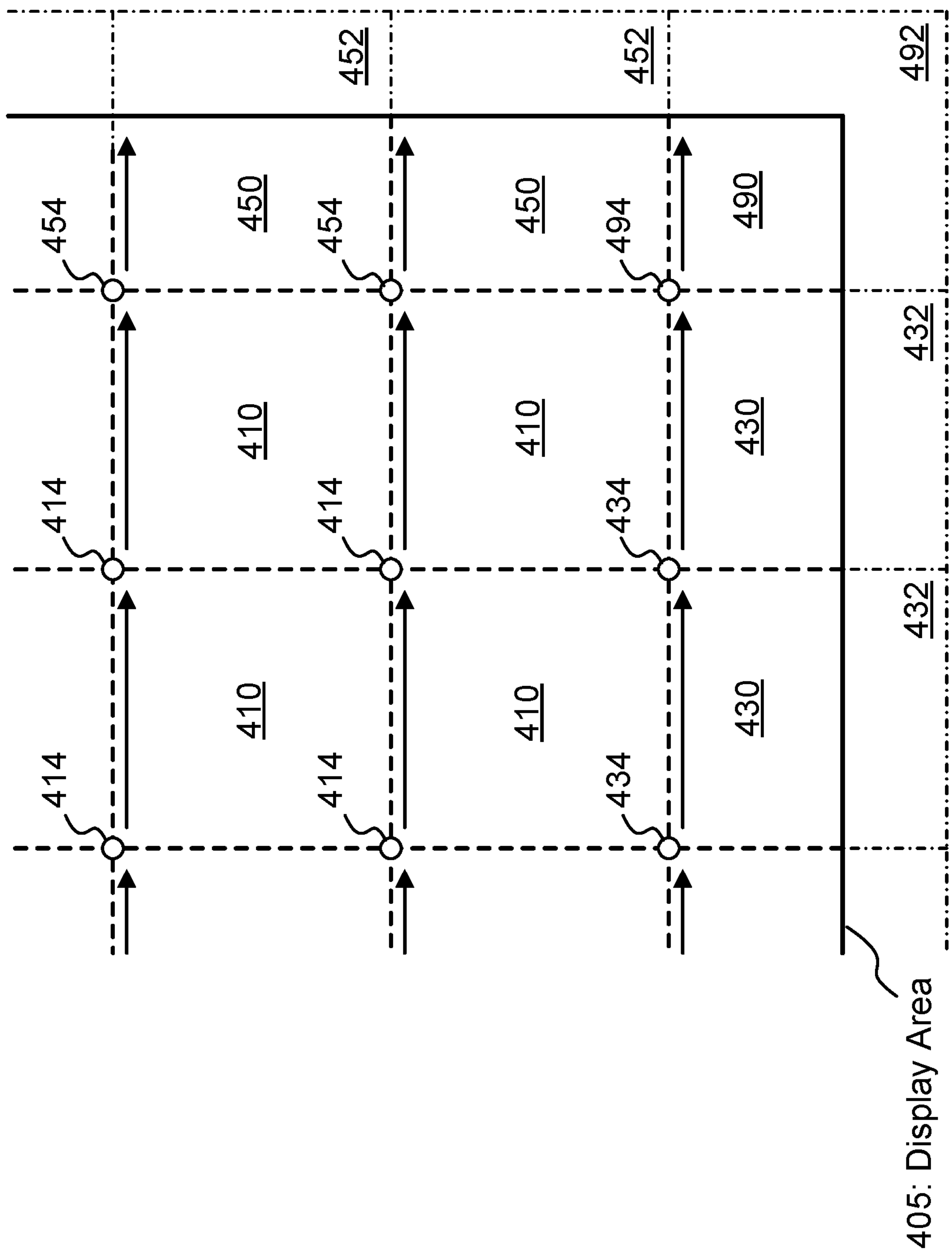

452
452
492
454
450
454
450
494
490
432
414
410
414
410
434
430
432
414
410
414
410
434
430
405: Display Area

FIG. 12D

1300

Illuminate a display area of a display panel by a backlight device comprising an array of light sources, wherein the display area is segmented into a plurality of zones corresponding to the light sources, respectively, the plurality of zones including inner zones corresponding to inner light sources and outmost zones corresponding to outmost light sources.

1302

Drive a plurality of pixels located in the display area based on respective pixel data of the pixels in the display area.

1304

Control a luminance level of a first outmost light source of the array of the light sources based on first pixel data of first pixels of the plurality of pixels, the first pixels being located in a first outmost zone of the outmost zones, the first outmost light source corresponding to the first outmost zone.

1306

FIG. 13

LOCAL DIMMING FOR PANEL DISPLAY DEVICES USING TWO-DIMENSIONAL LIGHT SOURCE ARRAY

TECHNICAL FIELD

[0001] This disclosure relates generally to panel display devices and more particularly to local dimming for panel display devices using a two-dimensional light source array.

BACKGROUND

[0002] Panel display devices with a light-transmissive display panel (e.g., a light-transmissive liquid crystal display (LCD) panel) may incorporate a backlight device that illuminates the light-transmissive display panel. Modern backlight devices, such as direct-lit backlights, full-array backlights etc., may be configured to illuminate a display panel with a two-dimensional (2D) array of light sources (e.g., light-emitting diodes (LEDs)). The use of a 2D light source array in a backlight device enables the implementation of a local dimming function that can achieve high dynamic contrast and low power consumption by individually controlling the respective light sources (e.g., light-emitting diodes (LEDs)) of the 2D light source array according to input image data.

SUMMARY

[0003] This summary is provided to introduce, in a simplified form, a selection of concepts that are further described below. This summary is not necessarily intended to identify key features or essential features of the present disclosure. The present disclosure may include the following various aspects and embodiments.

[0004] In an exemplary embodiment, the present disclosure provides a display device. The display device includes a backlight device, a driver circuit, and a backlight control circuit. The backlight device includes an array of light sources configured to illuminate a display area of a display panel. The display area is segmented into a plurality of zones corresponding to the light sources, respectively. The plurality of zones includes inner zones and outmost zones. The inner zones correspond to inner light sources of the array of light sources and are located apart from edges of the display area of the display panel. Each of the inner light sources are located at a center of a respective inner zone. The outmost zones are located along the edges of the display area of the display panel and correspond to outmost light sources of the array of light sources. Each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone. The driver circuit is configured to drive a plurality of pixels in the display area. The backlight control circuit is configured to control a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels, the first pixels being located in a first outmost zone of the outmost zones, the first outmost light source corresponding to the first outmost zone.

[0005] In another exemplary embodiment, the present disclosure provides a display driver that includes a driver circuit and a backlight control circuit. The driver circuit is configured to drive a plurality of pixels located in a display area of a display panel. The display area is illuminated by a backlight device that includes an array of light sources. The display area is segmented into a plurality of zones corresponding to the light sources, respectively. The plurality of zones include inner zones and outmost zones. The inner zones correspond to inner light sources of the array of light sources and are located apart from edges of the display area of the display panel. Each of inner light sources are located at a center of a respective inner zone. The outmost zones are located along the edges of the display and correspond to outmost light sources of the array of light sources. Each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone. The backlight control circuit is configured to control a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels. The first pixels are located in a first outmost zone of the outmost zones, and the first outmost light source corresponds to the first outmost zone.

[0006] In yet another exemplary embodiment, the present disclosure provides a method for local dimming. The method includes illuminating a display area of a display panel by a backlight device comprising an array of light sources. The display area is segmented into a plurality of zones corresponding to the light sources, respectively. The plurality of zones includes inner zones and outmost zones. The inner zones correspond to inner light sources of the array of light sources and are located apart from edges of the display area of the display panel. Each of the inner light sources are located at a center of a respective inner zone. The outmost zones are located along the edges of the display area of the display panel and correspond to outmost light sources of the array of light sources. Each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone. The method further includes driving a plurality of pixels located in the display area. The method further includes controlling a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels. The first pixels are located in a first outmost zone of the outmost zones, and the first outmost light source corresponds to the first outmost zone.

[0007] Other features and aspects are described in more detail below with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1**A shows an example configuration of a display device adapted to local dimming, according to one or more examples of the present disclosure.

[0009] FIG. **1**B shows example arrangements of zones of a display panel and light sources that illuminate the display panel, according to one or more examples of the present disclosure.

[0010] FIG. **2** shows an example of filter coefficients used to control the luminance level of a light source, according to one or more examples of the present disclosure.

[0011] FIG. **3**A shows an example configuration of a display device, according to one or more examples of the present disclosure.

[0012] FIG. **3**B is an enlarged view of example arrangements of zones and the light sources, according to one or more examples of the present disclosure.

[0013] FIG. **4**A shows an example definition of zones for a display panel, according to one or more embodiments.

[0014] FIG. **4**B shows an example of filter coefficients used to control the luminance level of a light source, according to one or more embodiments.

[0015] FIG. **5** shows an example configuration of a display device, according to one or more embodiments.

[0016] FIG. **6** shows an example arrangement of light sources of the backlight device and an example definition of zones for a display panel, according to one or more embodiments.

[0017] FIG. **7**A shows an enlarged view of the left top corner of a display area, according to one or more embodiments.

[0018] FIG. **7**B shows an enlarged view of the right top corner of the display area, according to one or more embodiments.

[0019] FIG. **7**C shows an enlarged view of the left bottom corner of the display area, according to one or more embodiments.

[0020] FIG. **7**D shows an enlarged view of the right bottom corner of the display area, according to one or more embodiments.

[0021] FIG. **8** shows an example configuration of a display driver, according to one or more embodiments.

[0022] FIG. **9** shows an example configuration of an image analysis circuit, according to one or more embodiments.

[0023] FIG. **10** shows an example definition of filter coefficients, according to one or more embodiments.

[0024] FIG. **11**A shows an example definition of filter coefficients for the case where all of a target zone and its adjacent zones are inner zones, according to one or more embodiments.

[0025] FIG. **11**B shows an example definition of filter coefficients for the case where a target zone and its adjacent zones include both inner zones and extended zones, according to one or more embodiments.

[0026] FIG. **11**C shows an example definition of filter coefficients for the case where a target zone is the left top corner zone, according to one or more embodiments.

[0027] FIGS. **12**A **12**B, **12**C, and **12**D show examples of starting points of respective zones, according to one or more embodiments.

[0028] FIG. **13** is a flowchart of an exemplary process for local dimming, according to one or more embodiments.

[0029] For ease of understanding, where possible, identical reference numerals have been used to designate elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be utilized in other embodiments without specific recitation. Suffixes may be appended to reference numerals to distinguish elements from one another. The drawings referenced herein are not to be construed as being drawn to scale unless specifically noted. In addition, the drawings are often simplified and details or components are omitted for clarity of presentation and explanation. The drawings and discussion serve to explain principles discussed below.

DETAILED DESCRIPTION

[0030] The following detailed description is exemplary in nature and is not intended to limit the disclosure or the applications and uses of the disclosure. Further, there is no intention to be bound by any expressed or implied theory presented in the preceding background, summary and brief description of the drawings, or in the following detailed description.

[0031] In the following detailed description, numerous specific details are set forth in order to provide a more thorough understanding of the disclosed technology. However, it will be apparent to one of ordinary skill in the art that the disclosed technology may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description.

[0032] The term "coupled" as used herein means connected directly to or connected through one or more intervening components or circuits. Further, throughout the application, ordinal numbers (e.g., first, second, third, etc.) may be used as an adjective for an element (i.e., any noun in the application). The use of ordinal numbers is not to imply or create any particular ordering of the elements nor to limit any element to being only a single element unless expressly disclosed, such as by the use of the terms "before", "after", "single", and other such terminology. Rather, the use of ordinal numbers is to distinguish between the elements. By way of an example, a first element is distinct from a second element, and the first element may encompass more than one element and succeed (or precede) the second element in an ordering of elements.

[0033] The present disclosure provides various techniques for achieving a local dimming function. Local dimming, as referred to herein, is a technique that individually controls the respective light sources (e.g., light-emitting diodes (LEDs)) of a 2D light source array according to input image data. By using the local dimming function, high dynamic contrast and low power consumption may be effectively achieved.

[0034] FIG. **1**A shows an example configuration of a display device **100** adapted to the local dimming, according to one or more examples of the present disclosure. In the shown example, a display device **100** includes a light-transmissive display panel **110** (e.g., a light-transmissive liquid crystal display (LCD) panel) and a backlight device **120** configured to illuminate the display panel **110**. The backlight device **120** includes a 2D array of light sources **122** each including a light emitting diode (LED) or other type of light emitting element.

[0035] To implement a local dimming function, the luminance levels of the respective light sources **122** may be individually controlled based on input image data. In some implementations, to enhance the contrast of the display image, the luminance levels of light sources **122** that illuminate portions of the display panel **110** that display bright images may be increased, while the luminance levels of light sources **122** that illuminate portions of the display panel **110** that display dark images may be decreased.

[0036] In various implementations, the luminance levels of the light sources **122** may be controlled based on "zones" defined for the display panel **110**. The zones **112** may be defined in rows and columns such that the zones **112** are in a one-to-one relationship with the light sources **122**, and the luminance levels of the respective light sources **122** may be controlled based on the images displayed in the corresponding zones **112**.

[0037] FIG. **1**B shows an example arrangement of the zones **112** of the display panel **110** and the light sources **122**, according to one or more examples of the present disclosure. In the shown example, the zones **112** are square in shape with the same size, and the projection of each light source **122** onto the display panel **110** is each located at the center of the corresponding zone **112**. It should be noted that when the projection of a light source **122** falls within a zone **112**, that zone **112** may be referred to as the corresponding zone **112** of the light source **122**. In FIG. **1**B, the numeral **112***a* denotes the corresponding zone of the light source **122***a*. In one implementation, the luminance level of each light source **122** may be controlled based on pixel data of pixels located in the corresponding zone **112** of that light source **122** and pixels located in the zones **112** adjacent to the corresponding zone **112**. In the example shown in FIG. **1**B, for example, the luminance level of the light source **122***a* may be controlled based on pixel data of the pixels located in the corresponding zone **112***a* and the eight zones **112** adjacent to the corresponding zone **112***a*. The box **130** indicates the 3×3 zones relevant to the control of the luminance level of the light source **122***a*.

[0038] Since the effect of the local dimming function varies depending on the light distribution characteristics (or light directivity characteristics) of the light sources **122**, it would be advantageous if the control of the luminance levels of the light sources **122** depends on the light distribution characteristics of the light sources **122**. One scheme to accomplish this is to perform filtering on pixel data depending on the light distribution characteristics of the light sources **122**. In one implementation, controlling the luminance level of a light source **122** may be accomplished by defining filter coefficients based on the light distribution characteristics of the light source **122**, applying the filter coefficients to pixel data of the pixels located in the corresponding zone **112***a* and its adjacent zones **112** to thereby produce filtered pixel data, and determining the luminance level of that light source **122** based on the filtered pixel data.

[0039] FIG. **2** shows an example of filter coefficients used to control the luminance level of the light source **122***a* (shown in FIG. **1**B), according to one or more examples of the present disclosure. In FIG. **2**, numeral **114***a* denotes the center of the corresponding zone **112***a* of the light source **122***a*, which coincides the location of the projection of the light source **122***a* onto the display panel **110**. In the shown example, the filter coefficients assigned to the pixels in the corresponding zone **112***a* and its adjacent zones **112** depend on the respective distances between the pixels and the center **114***a* of the corresponding zone **112***a*. The filter coefficient for the pixel positioned at the center **114***a* of the corresponding zone **112***a* is Wi (e.g., 1.0), which is the maximum filter coefficient. The filter coefficients determined for other pixels in the corresponding zone **112***a* and its adjacent zones **112** increase as the respective distances between the pixels and the center **114***a* of the corresponding zone **112***a* decrease. It should be noted that the filter coefficients are determined in symmetrically with respect to the center **114***a* of the corresponding zone **112***a* in view of the light distribution characteristics of the light source **122***a*. The filter coefficients used to control the luminance levels of other light sources **122** may be determined in a similar manner.

[0040] One issue is that the arrangement of the light sources of the backlight device may not match the arrangement of the zones. FIG. **3**A shows an example configuration of such a display device, denoted by numeral **200**, according to one or more examples of the present disclosure. The display device **200** includes a display panel **210** for which zones **212** are defined in rows and columns and a backlight device **220** that includes an array of light sources **222**. In the shown example, the zones **212** are defined with the same size and shape (e.g., the same width and height), as in typical implementations. The light sources **222** are arranged at regular intervals, but not necessary located at the centers of the corresponding zones **212**. For example, the outmost light sources **222** are located near the edge of the display panel **210**. Such situations may occur due to physical limitations of the arrangement of the light sources **222**, including the possible minimum spacing between adjacent light sources **222** and commercial availability of the backlight device **220**. Locating the outmost light sources **222** near the edge of the display panel **210** may also help to illuminate the periphery of the display panel **210** with sufficient luminance.

[0041] FIG. **3**B is an enlarged view of example arrangements of the zones **212** and the light sources **222**, according to one or more examples of the present disclosure. The box **230** indicates the 3×3 zones relevant to the control of the luminance level of the light source **222***a*, which include the corresponding zone **212***a* and its adjacent zones **212**. It should be noted that in implementations where the outmost light sources **222** are located near the edge of the display panel **210** with the zones **212** defined with the same size and shape, the light sources **222** may not be located at the centers of the corresponding zones **212**. In the example shown in FIG. **3**B, for example, the light source **222***a* located in the second row from the top and the second column from the left is not located at the center of its corresponding zone **212***a*, which is located in the second row from the top and the second column from the left in the array of the zones **212**. The gap between the location of each light source **222** and the center of its corresponding zone **212** may degrade the image quality of the display image displayed using the local dimming function. This is because the filter coefficients used to control the luminance level of each light source **222** are determined symmetrically with respect to the center of the corresponding zone **212** of that light source **222**, not symmetrically with respect to the location of that light source **222**.

[0042] In one aspect, the present disclosure provides local dimming techniques for improving the image quality even when the arrangement of the light sources of the backlight device does not match the arrangement of the zones defined for the display panel. The present disclosure recognizes that defining zones for a display panel with the same size and shape (or the same width and height) may result in a gap between the location of each light source and the center of its corresponding zone. Accordingly, in one or more embodiments of the present disclosure, zones used for implementing the local dimming function may be defined such that the outmost zones corresponding to the outmost light sources of the light source array are different in size or shape from the inter zones corresponding to the inner light sources of the light source array. The inner zones may be defined such that the inner light sources of the light source array are located at the centers of the respective inner zones. The outmost zones may be defined as the respective overlapping areas of "extended" zones and the display area of the display panel, wherein the extended zones are defined such that the extended zones have the same size and shape as their adjacent ones of the inner zones and the outmost light sources are located at the centers of the respective extended zones. The filter coefficients used for controlling each inner light source may be defined symmetrically with respect to the center of the corresponding inner zone of that inner light source. The filter coefficients used for controlling each outmost light source may be defined symmetrically with respect to the center of the corresponding "extended" zone of that outmost light source. This enables controlling the luminance levels of the outmost light sources in line with the light distribution characteristics of the outmost light sources. Various embodiments of the present disclosure are described in detail below.

[0043] FIG. **4**A shows an example definition of zones for a display panel, according to one or more embodiments. In the shown embodiments, numeral **310** denotes a display area of a display panel. The display area **310** is an area in which pixels are arranged to display an image. The display area **310** may be a portion of the display panel, and an array of zones is defined for the display panel by segmenting the display area **310**. The zones defined for the display area **310** include inner zones **312** and outmost zones **314**, **316**, and **318**. The inner zones **312** correspond to inner light sources **322** of the light source array and are located apart from the edges of the display area **310**. In various embodiments, the inner zones **312** are substantially rectangular. In the shown embodiment, the inner zones **312** are square in shape. Although FIG. **4**A shows that all of the inner zones **312** have the same size and shape, the sizes or shapes of the inner zones **312** may be non-uniform as long as the inner zones **312** form a rectangular array. In some implementations, the horizontal width of inner zones **312** in a first set of columns may be different from the horizontal width of inner zones **312** in a second set of columns. Additionally or alternatively, the vertical height of inner zones **312** in a first set of rows may be different from the vertical height of inner zones **312** in a second set of rows.

[0044] The outmost zones **314**, **316**, and **318** are located along the edges of the display area **310**. The outmost zones **314**, **316**, and **318** are different in size or shape from their adjacent ones of the inner zones **312**. The outmost zones **314**, which are located at the top edge of the display area **310**, may also be referred to as the top edge zones **314**. Similarly, the outmost zones **316**, which are located at the side edge of the display area **310**, may also be referred to as the side edge zones **316**, and the outmost zones **318** (one shown), which are located at the corners of the display area **310**, may also be referred to as the corner zones **318**.

[0045] The outmost zones **314** are defined as the overlapping areas of "extended" zones **334** and the display area **310**, wherein the "extended" zones **334** have the same size and shape as the inner zones **312** adjacent to the outmost zones **314**, respectively, and the outmost light sources **324** of the light source array are located at the centers of the "extended" zones **334**, respectively. It should be noted that the concept of the "extended" zones **334** is introduced only to define the outmost zones **314**, and therefore there are no pixels in the portions that are within the extended zones **334** but outside the display area **310**.

[0046] Similarly, the outmost zones **316** are defined as the overlapping areas of extended zones **336** and the display area **310**, wherein the extended zones **336** have the same size and shape as the inner zones **312** adjacent to the outmost zones **316**, respectively, and the outmost light sources **326** of the light source array are located at the centers of the "extended zones" **336**, respectively. Further, the outmost zone **318** is defined as the overlapping area of an extended zone **338** and the display area **310**, wherein the extended zone **338** has the same size and shape as the inner zone **312** diagonally adjacent to the outmost zone **318**. Although not shown in FIG. **4**A, those skilled in the art would appreciate that other inner zones and other outmost zones are defined for the remaining part of the display area **310** in a similar manner.

[0047] Referring to FIG. **4**B, the filter coefficients used to control the luminance level of each inner light source **322** may be defined symmetrically with respect to the center of the corresponding inner zone **312** of that inner light source **322**. For example, the box **330** indicates the 3×3 zones relevant to the control of the luminance level of the light source **322***a*, wherein the 3×3 zones include the corresponding zone **312***a*, the three inner zones **312** adjacent to the corresponding zone **312***a*, and the five "extended" zones **334**, **336**, and **338** adjacent to the corresponding zone **312***a*. The filter coefficients used for controlling the luminance level of the inner light source **322***a* may be defined symmetrically with respect to the center of the corresponding inner zone **312***a*. Similarly, the filter coefficients used for controlling the luminance level of each of the outmost light sources **324**, **326**, and **328** may be defined symmetrically with respect to the center of the corresponding "extended" zone **334**, **336**, or **338** of that outmost light source. Defining the filter coefficients in this manner enables performing the local dimming function based on the light distribution characteristics of the light sources **322**, **324**, **326**, and **328**, improving the image quality of the display image generated by the local dimming function.

[0048] FIG. **5** shows an example configuration of a display device **1000**, according to one or more embodiments. In the shown embodiment, the display device **1000** includes a display panel **400** and a display driver **600**. The display panel **400** includes a display area **405** in which pixels are arranged to display an image. The display panel **400** may be a light-transmissive display panel, such as an LCD panel. The display driver **600** is configured to drive the display panel **400** to display a desired image on the display panel **400**.

[0049] The display device **1000** further includes, a backlight device **500**, and a backlight driver **700**. The backlight device **500** is configured to illuminate the display area **405** of the display panel **400**. The backlight device **500** includes an array of light sources **505**. It should be noted that only some of the light sources **505** are shown in FIG. **5**, as the light sources **505** are located behind the display panel **400**. In one implementation, each light source **505** may include an LED or other type of light source. The backlight device **500** is coupled to the backlight driver **700**. The backlight driver **700** is configured to drive the light sources **505** of the backlight device **500** under the control of the display driver **600** so that each light source **505** emits light with a luminance level specified by the display driver **600**.

[0050] FIG. **6** shows an example arrangement of the light sources **505** of the backlight device **500** and an example definition of zones for the display panel **400**, according to one or more embodiments. The light sources **505** are arranged in rows and columns. While 288 light sources **505** are shown in FIG. **6**, those skilled in the art would appreciate that the backlight device **500** may include more or less than 288 light sources **505**. In actual implementations, the backlight device **500** may include from several hundred to several thousand light sources **505**. The zones are defined for the display panel **400** by segmenting the display area **405**. In the shown embodiment, the zones are substantially rectangular in shape. The defined zones include inner zones **410** and outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and

490. The inner zones **410** correspond to inner light sources of the array of light sources **505**, respectively, and are located apart from the edges of the display area **405**. Although FIG. **6** shows that all of the inner zones **410** have the same size and shape (or the same width and height), the sizes and/or shapes of the inner zones **410** may be non-uniform as long as the inner zones **410** form a rectangular array. In some implementations, the horizontal width of inner zones **410** in a first set of columns may be different from the horizontal width of inner zones **410** in a second set of columns. Additionally or alternatively, the vertical height of inner zones **410** in a first set of rows may be different from the vertical height of inner zones **312** in a second set of rows.

[0051] The outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490** are located along the edges of the display area **405** and correspond to outmost light sources of the array of light sources **505**, respectively. The outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490** are different in size or shape (or width and/or height) from their adjacent ones of the inner zones **410**.

[0052] The outmost zones **420**, **430**, **440**, and **450** are located at the edges of the display area **405**. More specifically, the outmost zones **420** are located at the top edge of the display area **405**, and therefore the outmost zones **420** may also be referred to as the top edge zones **420**. The outmost zones **430** are located at the bottom edge of the display area **405**, and therefore the outmost zones **430** may also be referred to as the bottom edge zones **430**. The outmost zones **440** are located at the left edge of the display area **405**, and therefore the outmost zones **440** may also be referred to as the left edge zones **440**. The outmost zones **450** are located at the right edge of the display area **405**, and therefore the outmost zones **450** may also be referred to as the right edge zones **450**.

[0053] The outmost zones **460**, **470**, **480**, and **490** are located at the corners of the display area **405**. The outmost zone **460** is located at the left top corner of the display area **405**, and therefore the outmost zone **460** may also be referred to as the left top corner zone **460**. The outmost zone **470** is located at the right top corner of the display area **405**, and therefore the outmost zone **470** may also be referred to as the right top corner zone **470**. The outmost zone **480** is located at the left bottom corner of the display area **405**, and therefore the outmost zone **480** may also be referred to as the left bottom corner zone **480**. The outmost zone **490** is located at the right bottom corner of the display area **405**, and therefore the outmost zone **490** may also be referred to as the right bottom corner zone **490**.

[0054] FIG. **7**A shows an enlarged view of the left top corner of the display area **405**, according to one or more embodiments. The inner zones **410** correspond to inner light sources **510**, respectively, and the respective inner light sources **510** are located at the centers of the corresponding inner zones **410**, respectively. The width and height of the inner zones **410** are $Xsize_{zone}$ and $Ysize_{zone}$, respectively. The inner zones **410** may be square in shape, i.e., $Xsize_{zone}$ and $Ysize_{zone}$ may be equal to each other.

[0055] As discussed above in relation to FIGS. **4**A and **4**B, the top edge zones **420**, the left edge zones **440**, and the left top corner zone **460** are defined using "extended" zones that have the same size and shape as their adjacent ones of the inner zones **410**, respectively. More specifically, the top edge zones **420** are respectively defined as the overlapping areas of the top edge extended zones **422** and the display area **405**, wherein the top edge extended zones **422** have the same size and shape as the inner zones **410** adjacent to the top edge zones **420**, and the top edge outmost light sources **520** are respectively located at the centers of the top edge extended zones **422**. The left edge zones **440** are respectively defined as the overlapping areas of the left edge extended zones **442** and the display area **405**, wherein the left edge extended zones **442** have the same size and shape as the inner zones **410** adjacent to the left edge zones **440**, and the left edge outmost light sources **540** are located at the centers of the left edge extended zones **442**, respectively. The left top corner zone **460** is defined as the overlapping area of a left top corner extended zone **462** and the display area **405**, wherein the left top corner extended zone **462** has the same size and shape as the inner zone **410** diagonally adjacent to the left top corner zone **460**, and the left top corner outmost light source **560** is located at the center of the left top corner extended zone **462**. In FIG. **7**A, "offset1" is the offset in the vertical direction between the top edge of the display area **405** and the top edges of the extended zones **422** and **462**, and "offset3" is the offset in the horizontal direction between the left edge of the display area **405** and the left edges of the extended zones **422** and **462**.

[0056] FIG. **7**B shows an enlarged view of the right top corner of the display area **405**, according to one or more embodiments. The right edge zones **450** and the right top corner zone **470** are defined in a manner similar to the top edge zones **420**, the left edge zones **440**, and the left top corner zone **460** shown in FIG. **7**A. More specifically, the right edge zones **450** are respectively defined as the overlapping areas of the right edge extended zones **452** and the display area **405**, wherein the right edge extended zones **452** have the same size and shape as the inner zones **410** adjacent to the right edge zones **450**, and the right edge outmost light sources **550** are located at the centers of the right edge extended zones **452**, respectively. The right top corner zone **470** is defined as the overlapping area of the right top corner extended zone **472** and the display area **405**, wherein the right top corner extended zone **472** has the same size and shape as the inner zone **410** diagonally adjacent to the right top corner zone **470**, and the right top corner outmost light source **570** is located at the center of the right top corner extended zones **472**. In FIG. **7**B, "offset4" is the offset in the horizontal direction between the right edge of the display area **405** and the right edges of the extended zones **452** and **472**.

[0057] FIG. **7**C shows an enlarged view of the left bottom corner of the display area **405**, according to one or more embodiments. The bottom edge zones **430** and the left bottom corner zone **480** are defined in a manner similar to the top edge zones **420** and the left top corner zone **460** shown in FIG. **7**A. More specifically, the bottom edge zones **430** are respectively defined as the overlapping areas of the bottom edge extended zones **432** and the display area **405**, wherein the bottom edge extended zones **432** have the same size and shape as the inner zones **410** adjacent to the bottom edge zones **430**, and the bottom edge outmost light sources **530** are located at the centers of the bottom edge extended zones **432**, respectively. The left bottom corner zone **480** is defined as the overlapping area of the left bottom corner extended zone **482** and the display area **405**, wherein the left bottom corner extended zone **482** has the same size and shape as the inner zone **410** diagonally adjacent to the left bottom corner zone **480**, and the left bottom corner outmost light source **580** is located at the center of the left bottom corner extended zone **482**. In FIG. **7**C, “offset2” is the offset between the bottom edge of the display area **405** and the bottom edges of the extended zones **432** and **482** in the vertical direction.

[0058] FIG. **7**D shows an enlarged view of the right bottom corner of the display area **405**, according to one or more embodiments. The right bottom corner zone **490** is defined in a manner similar to the right top corner zones **470** shown in FIG. **7**B. More specifically, the right bottom corner zones **490** is defined as the overlapping area of the right bottom corner extended zone **492** and the display area **405**, wherein the right bottom corner extended zone **492** has the same size and shape as the inner zone **410** diagonally adjacent to the right bottom corner zone **490**, and the right bottom corner outmost light source **590** is located at the center of the right bottom corner extended zone **492**.

[0059] FIG. **8** shows an example configuration of the display driver **600**, according to one or more embodiments. In the shown embodiment, the display driver **600** includes an image processing circuit **610**, a driver circuit **620**, a backlight control circuit **630**, and a storage **660**. The display driver **600** is configured to receive input image data corresponding to the display image. In one implementation, each pixel of the display panel **400** may include red (R), green (G), and blue (B) subpixels configured to display red, green, and blue colors, respectively, and the input image data may include R, G, and B graylevels for each pixel, wherein the R, G, and B graylevels specify the luminance levels of the R, G, and B subpixels, respectively.

[0060] The image processing circuit **610** is configured to perform image processing on the input image data to produce processed image data. The image processing performed by the image processing circuit **610** may include color adjustment, demura correction, deburn correction, image scaling, gamma transformation, or other image processing.

[0061] The driver circuit **620** is configured to receive the processed image data from the image processing circuit **610** and drive respective pixels of the display panel **400** based at least in part on the processed image data. In one implementation, each pixel of the display panel **400** may include R, G, and B subpixels and the processed image data may include the graylevels of the R, G, and B subpixels for each pixel. The driver circuit **620** may be configured to drive or update the R, G, and B subpixels of each pixel based at least in part on the processed image data to control the luminance levels of the R, G, and B subpixels as specified by the processed image data.

[0062] The backlight control circuit **630** is configured to generate backlight values for the respective light sources **505** based at least in part on the input image data and to provide the backlight values to the backlight driver **700** to control the luminance levels of the respective light sources **505** (shown in FIGS. **5** and **6**) of the backlight device **500**. The backlight values for the light sources **505** may indicate specified luminance levels of the respective light sources **505**. The backlight driver **700** is configured to drive the respective light sources **505** based on the backlight values to cause the respective light sources **505** to emit light with the specified luminance levels. The backlight values are generated by the local dimming function based on the input image data. As discussed in detail later, the local dimming function is achieved using the inner zones **410** and the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490** shown in FIGS. **6** and **7**A to **7**D.

[0063] In the shown embodiments, the backlight control circuit **630** includes an image analysis circuit **640** and a backlight value generation circuit **650**. The image analysis circuit **640** is configured to analyze the input image data and to generate local average picture levels (APLs) of the respective zones (including the inner zones **410** and the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490**) based on the input image data. The local APL of a zone may be a value representing the luminance of the image displayed in the zone and in its adjacent part of the display area **405**. In some implementations, the local APLs of the respective zones may be provided to the image processing circuit **610**, and image processing may be applied to the input image data depending on the local APLs. The image analysis circuit **640** is further configured to generate the base backlight values based on the result of the analysis of the input image data. The backlight value generation circuit **650** is configured to generate the backlight values for the respective light sources **505** by modifying the base backlight values based on a display brightness value (DBV). The DBV referred to herein is a value that specifies a desired display brightness level of the display device **1000**, wherein the display brightness level referred to herein is the overall brightness level of the display image displayed on the display panel **400**. The DBV may be generated by an external controller based on a user operation. For example, when a command to adjust the display brightness level of the display device **1000** is manually entered into an input device, the DBV may be generated based on that command. In one implementation, the backlight value generation circuit **650** may be configured to generate the backlight values for the respective light sources **505** by multiplying the base backlight values by a multiplication factor determined based on the DBV.

[0064] FIG. **9** shows an example configuration of the image analysis circuit **640**, according to one or more embodiments. In the shown embodiment, the image analysis circuit **640** is configured to receive coordinates of a target light source, which is a light source for which the base backlight value is currently being calculated. The corresponding zone of the target light source may also be referred to as the target zone. The image analysis circuit **640** is configured to calculate, in response to receiving the coordinates of a target light source, the base backlight value of the target light source and the local APL of the target zone. In the shown embodiment, the image analysis circuit **640** includes a filter circuit **642**, an accumulator circuit **644**, and an APL and backlight value (BL) calculator circuit **646**.

[0065] The filter circuit **642** is configured to extract pixel data used to calculate the base backlight value of the target light source and the local APL of the target zone, and to apply filtering to the pixel data to produce filtered pixel data. Here, the pixel data of a pixel is indicative of the luminance level of that pixel which may be calculated from the R, G, and B graylevels of that pixel. The filtered pixel data is provided to the accumulator circuit **644**.

[0066] FIG. **10** shows an example definition of filter coefficients used for the filtering, according to one or more embodiments. In calculating the base backlight value of the target light source (which is located at the center of the target zone) and the local APL of the target zone, the filtering is applied to pixel data of pixels located in the target zone and its eight adjacent zones, which are arranged in three rows and three columns. In FIG. **10**, numeral **800** denotes the 3×3 zones relevant to the filtering for the target zone, numeral **810** denotes the target zone, numeral **815** denotes the center of the target zone **810**, and numerals **820** denote its adjacent zones of the target zone **810**. In the shown example, the xy coordinates of the pixel positioned at the center **815** of the target zone **810** are (x_C, y_C), and the filter coefficient for the pixel positioned at the center **815** of the target zone **810** is W (x_C, y_C) (e.g., 1.0), which is the maximum filter coefficient. The filter coefficients defined for other pixels in the target zone **810** and its adjacent zones **820** increase as the respective distances between the pixels and the center **815** of the target zone **810** decrease. Although FIG. **10** shows all of the target zone and its eight adjacent zones are inner zones, it should be noted that some of the target zone **810** and its adjacent zones **820** may be extended zones (shown in FIGS. **6** and **7**A to **7**D). Details of the calculation of the filter coefficients in such cases will be described later.

[0067] Referring back to FIG. **9**, the filter circuit **642** is configured to store filter data **648** used to generate the filter coefficients assigned to the pixels in the target zone and its adjacent zones through arithmetic processing. Because there may be a large number of pixels in the target zone and its adjacent zones, it may be impractical to store the original filter coefficients assigned to the pixels in the target zone and its adjacent zones. To address this, the filter circuit **642** may be configured to store the filter data **648** and to generate the filter coefficients for the respective pixels in the target zone and its adjacent zones from the filter data **648**. The filter data **648** may contain information sufficient to reproduce the filter coefficients. In some implementations, the filter data **648** may include filter coefficients assigned to predetermined ones (but not all) of the pixels in the target zone and its adjacent zones, and the filter circuit **642** may be configured to calculate filter coefficients assigned to the remaining pixels by interpolating the filter coefficients assigned to the predetermined pixels. In other implementations, the filter data **648** may be configured to store the filter coefficients themselves assigned to the pixels in the target zone and its adjacent zones.

[0068] In connection with the fact that the target zone and its adjacent zones are arranged in three rows and three columns, there may be cases where all of the target zone **810** and its adjacent zones **820** are inner zones, and cases where some of the target zone **810** and its adjacent zones **820** are extended zones (shown in FIGS. **6** and **7**A to **7**D). FIGS. **11**A to **11**C show examples of the target zone and its adjacent zones, according to one or more embodiments.

[0069] FIG. **11**A shows an example definition of filter coefficients for the case where all of the target zone and its adjacent zones are inner zones **410**, according to one or more embodiments, wherein the numeral **800*a*** denotes the 3×3 zones relevant to the filtering for the target zone, numeral **815*a*** denotes the center of the target zone. When the 3×3 zones **800*a*** are all inner zones **410**, the filter coefficients are calculated for all the pixels in the 3×3 zones **800*a*** using the filter data **648**.

[0070] FIG. **11**B shows an example definition of filter coefficients for the case where the target zone and its adjacent zones include both of inner zones and extended zones, according to one or more embodiments. In FIG. **11**B, the numeral **800*b*** denotes the 3×3 zones relevant to filtering for the target zone, numeral **815*b*** denotes the center of the target zone. In the shown example, the 3×3 zones **800*b*** include four inner zones **410** and five extended zones **422**, **442**, and **462**, wherein the two extended zones **422** are used to define the two top edge zones **420**, the two extended zones **442** are used to define the two left edge zones **440**, and the extended zone **462** is used to define the left top corner zone **460**. In this case, the filter coefficients are calculated for the pixels located in the portion of the display area **405** within the 3×3 zones **800*b***. It should be noted that there are no pixels outside the display area **405**.

[0071] The filter coefficients for the pixels of the four inner zones **410**, the two top edge zones **420**, the two left edge zones **440**, and the left top corner zone **460** are calculated to be equal to the filter coefficients calculated for the corresponding pixels of the 3×3 zones **800** shown in FIG. **10**, which are all inner zones. For example, the filter coefficients for the pixels of the left top corner zone **460**, which is the right bottom portion of the zone located at the left top of the 3×3 zones **800*b***, are calculated to be equal to the filter coefficients for the corresponding pixels of the right bottom part of the zone located at the left top of the 3×3 inner zones **800** shown in FIG. **10**.

[0072] When the target zone is one of the outmost zones, some of the 3×3 zones relevant to the filtering may be "dummy" zones in which there are no pixels. FIG. **11**C shows an example definition of filter coefficients for the case where the target zone is the left top corner zone **460**, according to one or more embodiments. In FIG. **11**C, the numeral **800*c*** denotes the 3×3 zones relevant to the filtering for the target zone, numeral **815*c*** denotes the center of the extended zone used to define the target zone. In the shown example, the 3×3 zones **800*c*** relevant to the filtering include five "dummy" zones **830**, one inner zone **410**, one top edge zone **420**, one left edge zones **440**, and one left top corner zone **460**. In this case, similarly to the case shown in FIG. **11**B, the filter coefficients for the pixels in the inner zone **410**, the top edge zones **420**, the left edge zone **440**, and the left top corner zone **460** are calculated to be equal to the filter coefficients calculated for the corresponding pixels of the 3×3 zones **800** shown in FIG. **10**. For example, the filter coefficients for the pixels of the left top corner zone **460**, which is the right bottom portion of the target zone, are calculated to be equal to the filter coefficients for the corresponding pixels of the right bottom part of the zone located at the center of the 3×3 zones **800**.

[0073] FIGS. **12**A, **12**B, **12**C, and **12**D show examples of the "starting points" of the respective zones, including inner zones and outmost zones, according to one or more embodiments. The "starting point" of a zone referred here is the pixel position of that zone at which the calculation of the filter coefficients for the pixels of that zone is to be started. In the shown embodiments, the "starting point" of the zone is defined at the left top corner of that zone, and the order of the calculation of the filter coefficients for the pixels of each zone is from left to right and from top to bottom, which is in accordance with a typical circuit operation.

[0074] In FIGS. **12**A, **12**B, **12**C, and **12**D, numerals **414** indicate the starting points of the inner zones **410**. The starting points **414** of the inner zones **410** are at the left top corners of the respective inner zones **410**. The filter circuit **642** (shown in FIG. **9**) is configured to successively calculate the filter coefficients of the respective pixels in the inner zones **410** based on the positions of the starting points of the inner zones **410**.

[0075] Further, numerals **424**, **444**, and **464** in FIG. **12**A indicate the starting points of the outmost zones **420**, **440**, and **460**, respectively, and numerals **454** and **474** in FIG. **12**B indicate the starting points of the outmost zones **450** and **470**. Further, numerals **434** and **484** in FIG. **12**C indicate the starting points of the outmost zones **430** and **480**, and numeral **494** in FIG. **12**D indicates the starting point of the outmost zone **490**. The starting points **424**, **434**, **444**, **454**, **464**, **474**, **484**, and **494** of the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490** are at the left top corners of the respective outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490**. The filter circuit **642** (shown in FIG. **9**) is configured to successively calculate the filter coefficients of the respective pixels in the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490** based on the positions of the starting points of the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490**.

[0076] The position of the starting point of an outmost zone in the extended zone defining that outmost zone indicates which of the filter coefficients shown in FIG. **10** are to be used for the filtering of the pixel data of the pixels of that outmost zone. For example, the position of the starting point **464** of the left top corner zone **460** in the extended zone **462** indicates which of the filter coefficients shown in FIG. **10** are to be used for the filtering of the pixel data of the pixels of the left top corner zone **460** (see also FIGS. **11**B and **11**C). The position of the starting point **464** of the left top corner zone **460** in the extended zone **462** may correspond to the offset "offset1" and the offset "offset3" shown in FIG. **7**A. A similar goes for the starting points of other outmost zones **420**, **430**, **440**, **450**, **470**, **480**, and **490** in connection with the offsets "offset1" and "offset3" shown in FIGS. **7**A to **7**D.

[0077] In one implementation, the filter circuit **642** may be configured to calculate the filter coefficients for the pixels of each outmost zone based on the position of the starting point of that outmost zone in the extended zone defining that outmost zone. For example, the filter circuit **642** may be configured to calculate the filter coefficients for the pixels of the left top corner zone **460** based on the position of the starting point **464** of the left top corner zone **460** in the extended zone **462**.

[0078] Referring back to FIG. **9**, the filter circuit **642** is configured to receive initialization values that correspond to the positions of the starting points **414**, **424**, **444**, and **464** of the inner zones **410**, the top edge zones **420**, the left edge zones **440**, and the left top corner zone **460**, and to calculate the filter coefficients for the pixels of the respective zones (including the inner zones and the outmost zones). In one implementation, the storage **660** shown in FIG. **8** may be configured to store the initialization values to provide the initialization values to the filter circuit **642**. It should be noted that the positions of the starting points of the inner zones **410**, the top edge zones **420**, the left edge zones **440**, and the left top corner zone **460** contain sufficient information to calculate the filter coefficients of the pixels in all the zones, including the inner zones and the outmost zones. This is because:

[0079] (a) the position of the starting point **474** of the right top corner zone **470** in the extended zone **472** is equivalent to the position in the starting point **424** of the top edge zone **420** in the extended zone **422** (see FIG. **12**B),

[0080] (b) the position of the starting point **484** of the left bottom corner zone **480** in the extended zone **482** is equivalent to the position in the starting point **444** of the left edge zone **440** in the extended zone **442** (see FIG. **12**C),

[0081] (c) the positions of the starting points **434**, **454**, and **494** of the bottom edge zones **430**, **450** and **490** are at the left top corners of the extended zones **432**, **452**, and **492** (see FIGS. **12**B, **12**C, and **12**D), respectively, and

[0082] (d) the end-of-data of pixel data of each pixel row, the end-of-data of pixel data of each pixel column, and the end-of-data of pixel data of each outmost zone indicate the end of the calculation of the filter coefficients for each pixel row, each pixel column, and each outmost zone, respectively.

[0083] The filter circuit **642** is further configured to apply the filter coefficients to the pixel data of the respective zones, thereby producing filtered pixel data. The filter circuit **642** is further configured to provide the filtered pixel data to the accumulator circuit **644**.

[0084] The accumulator circuit **644** is configured to accumulate, for each zone, values of filtered pixel data of the 3×3 zones that include that zone and its adjacent eight zones to calculate a filtered sum for each zone. The filtered sum for each zone is the sum of the values of the filtered pixel data of the pixels of the 3×3 zones that includes that zone and its eight adjacent zones. In one implementation, the filtered sum for a target zone, which may be an inner zone or an outmost zone, may be calculated according to the following expression (1):

$$\mathrm{SUM} = \sum_i w(i) \cdot pix(i), \tag{1}$$

where SUM is the filtered sum for the target zone, Σ represents the sum for the pixels in the target zone and its eight adjacent zones, w (i) is the filter coefficient for pixel i, and pix (i) is the value of the pixel data of pixel i.

[0085] The following is a detailed description of the calculation of the filtered sum for a target zone with zone indices (X_{LS}, Y_{LS}). Here X_{LS} is an X index that indicates the horizontal location in the array of the zones, and is an integer between 0 and M−1, inclusive, where M is the number of the columns of the zones of the display area **405**. The target zone with an X index of X_{LS} is located in the (X_{LS}+1)-th column of the zone array from the left. Y_{LS} is a Y index that indicates the vertical location in the array of the zones, and is an integer between 0 and N−1, inclusive, where N is the number of the rows of the zones of the display area **405**. The target zone with a Y index of Y_{LS} is located in the (Y_{LS}+1)-th row of the array of the zones from the top. The notations used in the following description are as follows.

[0086] (x, y) are xy coordinates in the xy coordinate system defined for the filter shown in FIG. **10** and w (x, y) is the filter coefficient for a pixel with coordinates (x, y), which are defined in the xy coordinate system shown in FIG. **10**. It should be noted that the origin O of the xy coordinate system is at the left top corner of the target zone. (X, Y) are XY coordinates in the coordinate system defined for the display area **405** of the display panel **400** as shown in FIG. **6**.

[0087] $xsize_{filter}$ is the horizontal size of the 3×3 zones that contains the target zone and its adjacent zones, and $ysize_{filter}$ is the vertical size of the 3×3 zones. The horizonal size $xsize_{filter}$ and the vertical size $ysize_{filter}$ are expressed using the horizontal and vertical sizes $Xsize_{zone}$ and $Ysize_{zone}$ of the inner zones and the extended zones (see FIG. **7**A) as follows:

$$xsize_{filter} = 3 \times Xsize_{zone},$$

and

$$ysize_{filter} = 3 \times Ysize_{zone}.$$

[0088] X_{filter} and Y_{filter} are the xy coordinates of the left top corner of the 3×3 zones that contains the target zone and its adjacent zones, in the coordinate system shown in FIG. **10**. X_{filter} and Y filter are expressed using $xsize_{filter}$ and $ysize_{filter}$ as follows:

$$(X_{filter}, Y_{filter}) = \left(-xsize_{filter}/3,\ -ysize_{filter}/3\right).$$

[0089] When the target zone is one of the inner zones **410** with zone indices (X_{LS}, Y_{LS}), the filtered sum SUM (X_{LS}, Y_{LS}) is calculated in accordance with the following expression (2):

$$\text{SUM}\ (X_{LS}, Y_{LS}) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter}} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter}} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y), \tag{2}$$

[0090] where X_{pix} and Y_{pix} are XY coordinates of the left top corner of the target zone, w (x, y) is the filter coefficient for a pixel with coordinates (x, y), and pix (X, Y) is the value of pixel data of the pixel with XY coordinates (X, Y).

[0091] When the target zone is the left top corner zone **460**, which has zone indices (0, 0), the filtered sum SUM (0, 0) is calculated in accordance with the following expression (3):

$$\text{SUM}\ (0, 0) = \sum_{y=offset1}^{Y_{filter}+ysize_{filter}} \sum_{x=offset3}^{X_{filter}+xsize_{filter}} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y), \tag{3}$$

where, as shown in FIG. **7**A, "offset1" is the offset in the vertical direction between the top edge of the display area **405** and the top edges of the extended zones **422** and **462**, and "offset3" is the offset in the horizontal direction between the left edge of the display area **405** and the left edges of the extended zones **442** and **462**.

[0092] When the target zone is one of the top edge zones **420** with zone indices (X_{LS}, 0), the filtered sum SUM (X_{LS}, 0) is calculated in accordance with the following expression (4):

$$\text{SUM}\ (X_{LS}, 0) = \sum_{y=offset1}^{Y_{filter}+ysize_{filter}} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter}} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y). \tag{4}$$

[0093] When the target zone is the right top corner zone **470**, which has zone indices (N−1, 0), the filtered sum SUM (N−1, 0) is calculated in accordance with the following expression (5):

$$\text{SUM}\ (N, 1, 0) = \sum_{y=offset1}^{Y_{filter}+ysize_{filter}} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter}-offset4} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y), \tag{5}$$

where "offset4" is the offset in the horizontal direction between the right edge of the display area **405** and the right edges of the extended zones **452** and **472** as shown in FIG. **7**B.

[0094] When the target zone is one of the left edge zones **440** with zone indices (0, Y_{LS}), the filtered sum SUM (0, Y_{LS}) is calculated in accordance with the following expression (6):

$$\text{SUM}\ (0, Y_{LS}) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter}} \sum_{x=offset3}^{X_{filter}+xsize_{filter}} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y). \tag{6}$$

[0095] When the target zone is one of the right edge zones **450** with zone indices (N−1, Y_{LS}), the filtered sum SUM (N−1, Y_{LS}) is calculated in accordance with the following expression (7):

$$\text{SUM}\ (N-1, Y_{LS}) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter}} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter}-offset4} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y). \tag{7}$$

[0096] When the target zone is the left bottom corner zone **480**, which has zone indices (0, M−1), the filtered sum SUM (0, M−1) is calculated in accordance with the following expression (8):

$$\text{SUM}\ (0, M-1) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter}-offset2} \sum_{x=offset3}^{X_{filter}+xsize_{filter}} w(x, y) \cdot pix(X_{pix} + x, Y_{pix} + y), \tag{8}$$

where "offset2" is the offset between the bottom edge of the display area **405** and the bottom edges of the extended zones **432** and **482** in the vertical direction as shown in FIG. **7**C.

[0097] When the target zone is one of the bottom edge zones **430** with zone indices (X_{LS}, M−1), the filtered sum SUM (X_{LS}, M−1) is calculated in accordance with the following expression (9):

$$\mathrm{SUM}\,(X_{LS}, M-1) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter-offset2}} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter}} w(x, y)\cdot pix(X_{pix}+x, Y_{pix}+y). \tag{9}$$

[0098] When the target zone is the right bottom corner zone **490**, which has the zone indices (N−1, M−1), the filtered sum SUM (N−1, M−1) is calculated in accordance with the following expression (10):

$$\mathrm{SUM}\,(\mathrm{N}-1, M-1) = \sum_{y=Y_{filter}}^{Y_{filter}+ysize_{filter}-offset2} \sum_{x=X_{filter}}^{X_{filter}+xsize_{filter-offset4}} w(x, y)\cdot pix(X_{pix}+x, Y_{pix}+y). \tag{10}$$

[0099] With further reference to FIG. **9**, the APL and BL calculator circuit **646** is configured to receive the filtered sum for each zone from the accumulator circuit **644** to calculate a local APL for each zone based on the filtered sum for that zone. As discussed above, the local APL of a zone may be a value representing the luminance of the image displayed in the zone and in its adjacent part of the display area **405**. In one implementation, the APL and BL calculator circuit **646** may be configured to calculate the local APL for each zone by normalizing the filtered sum for each zone with a normalization value determined for that zone, e.g., by dividing the filtered sum for each zone by the normalization value determined for that zone. The normalization value for a target zone corresponds to the sum of the filter coefficients for pixels in the target zone and its adjacent zones multiplied by the maximum value of the pixel data. In one implementation, the normalization value for the target zone is the sum of the filter coefficients for pixels in the target zone and its adjacent zones multiplied by the maximum value of the pixel data. In one or more embodiments, the normalization value for a target zone may be represented by the following equation (11):

$$\text{Normalization Value} = \sum_{i} w(i)\cdot Pix_{max}, \tag{11}$$

where Σ represents the sum for the pixels in the target zone and its adjacent zones, w (i) is the filter coefficient for pixel i in the target zone and its adjacent zones, and Pix_{max} is the maximum value of the pixel data. In implementations where pixel data is 10-bit data, Pix_{max} is 1023.

[0100] In one implementation, the APL and BL calculator circuit **646** may be configured to receive normalization values for the inner zones **410**, the top edge zones **420**, the bottom edge zones **430**, the left edge zones **440**, the right edge zones **450**, the left top corner zone **460**, the right top corner zone **470**, the left bottom corner zone **480**, and the right bottom corner zone **490**. The APL and BL calculator circuit **646** may be further configured to select an appropriate one of the received normalization values depending on the type of the target zone and calculate the local APL for the target zone using the selected normalization value. For example, the APL and BL calculator circuit **646** may be configured to, when the target zone is an inner zone **410**, select the normalization value of the inner zones **410** and calculate the local APL for the target zone by dividing the filtered sum for the target zone by the selected normalization value. In another example, the APL and BL calculator circuit **646** may be further configured to, when the target zone is a top edge zone **420**, select the normalization value of the top edge zones **420** and calculate the local APL for the target zone by dividing the filtered sum for the target zone by the selected normalization value. A similar goes for other types of zones.

[0101] The APL and BL calculator circuit **646** is further configured to calculate the base backlight value for each light source **505** based on the local APL of the corresponding zone of that light source **505**. In one implementation, the base backlight value for each light source **505** may increase as the local APL of the corresponding zone of that light source **505** increases. The base backlight value calculated for each light source **505** is provided to the backlight value generation circuit **650** (shown in FIG. **8**), and used to determine the backlight value for that light source **505** to control the luminance level of that light source **505**.

[0102] FIG. **13** is a flowchart of an exemplary process for local dimming, according to one or more embodiments. The process **1300** may be performed by the display device **1000** and in particular, the display driver **600** shown in FIG. **5**. However, it will be recognized that a display device that includes additional and/or fewer components as shown in FIG. **5** may be used to perform the process **1300**, that any of the following steps may be performed in any suitable order, and that the process **1300** may be performed in any suitable environment.

[0103] In step **1302**, a backlight device (e.g., the backlight device **500** shown in FIG. **5**) including an array of light sources (e.g., the light sources **505**) illuminates a display area (e.g. the display area **310** shown in FIG. **4**A and the display area **405** shown in FIGS. **6** and **7**A to **7**D) of a display panel (e.g. the display panel **400**). The display area is segmented into a plurality of zones corresponding to the light sources, respectively. The plurality of zones includes inner zones (e.g., the inner zones **312** shown in FIG. **4**A and the inner zones **410** shown in FIG. **7**A to **7**D) corresponding to inner light sources (e.g., the light sources **322** shown in FIG. **4**A and the light sources **510** in FIGS. **7**A to **7**D) of the array of light sources and outmost zones (e.g., the outmost zones **334**, **337**, and **338** shown in FIG. **4**A and the outmost zones **420**, **430**, **440**, **450**, **460**, **470**, **480**, and **490**) shown in FIGS. **7**A to **7**D) corresponding to outmost light sources (e.g., the outmost light sources **324**, **327**, and **328** shown in FIG. **4**A and the outmost light sources **520**, **530**, **540**, **550**, **560**, **570**, **580**, and **590** shown in FIGS. **7**A to **7**D) of the array of light sources. The inner zones are located apart from edges of the display area of the display panel, and each of the inner light sources is each located at a center of a respective inner zone. The outmost zones are located along the edges of the display area of the display panel. Each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone.

[0104] In step **1304**, a display driver (e.g., the display driver **600** shown in FIGS. **5** and **8**), drives a plurality of pixels located in the display area based on respective pixel data of the pixels in the display area.

[0105] In step **1306**, the display driver controls a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels. The first pixels are located in a first outmost zone of the outmost zones, and the first outmost light source corresponds to the first outmost zone.

[0106] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0107] The use of the terms "a" and "an" and "the" and "at least one" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term "at least one" followed by a list of one or more items (for example, "at least one of A and B") is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0108] Exemplary embodiments are described herein. Variations of those exemplary embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

1. A display device, comprising:

a backlight device comprising an array of light sources configured to illuminate a display area of a display panel, wherein the display area is segmented into a plurality of zones corresponding to the light sources, respectively, the plurality of zones comprising:

inner zones corresponding to inner light sources of the array of light sources, wherein the inner zones are located apart from edges of the display area of the display panel, and wherein each of the inner light sources is located at a center of a respective inner zone; and

outmost zones located along the edges of the display area of the display panel and corresponding to outmost light sources of the array of light sources, wherein each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone:

a driver circuit configured to drive a plurality of pixels in the display area; and

a backlight control circuit configured to control a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels, the first pixels being located in a first outmost zone of the outmost zones, the first outmost light source corresponding to the first outmost zone.

2. The display device of claim **1**, wherein the first outmost zone is defined to be an overlapping area of an extended zone and the display area of the display panel, and

wherein the extended zone is defined such that the extended zone has the same size and shape as a first inner zone of the inner zones and that the first outmost light source is located at the center of the extended zone, and

wherein the first inner zone is adjacent to the first outmost zone.

3. The display device of claim **2**, wherein the backlight control circuit is further configured to:

receive an initialization value corresponding to a position of a corner of the first outmost zone in the extended zone:

determine, based on the initialization value, filter coefficients for the first pixels located in the first outmost zone; and

apply the determined filter coefficients to the first pixel data of the first pixels located in the first outmost zone to generate filtered pixel data of the first pixels, and

wherein controlling the luminance level of the first outmost light source is based on the filtered pixel data of the first pixels.

4. The display device of claim **2**, wherein controlling the luminance level of the first outmost light source is further based on second pixel data of second pixels of the plurality of pixels, the second pixels being located in adjacent zones of the plurality of zones, the adjacent zones being adjacent to the first outmost zone.

5. The display device of claim **4**, wherein the backlight control circuit is further configured to:

receive an initialization value corresponding to a position of a corner of the first outmost zone in the extended zone:

determine, based on the initialization value, filter coefficients for the first pixels located in the first outmost zone and the second pixels located in the adjacent zones; and

apply the determined filter coefficients to the first pixel data of the first pixels and the second pixel data of the second pixels to generate filtered pixel data of the first pixels and the second pixels, and

wherein controlling the luminance level of the first outmost light source is based on the filtered pixel data of the first pixels and the second pixels.

6. The display device of claim **5**, wherein the backlight control circuit is further configured to determine a sum of values of the filtered pixel data of the first pixels and the second pixels, and wherein controlling the luminance level of the first outmost light source is based on the sum of the values of the filtered pixel data.

7. The display device of claim **6**, wherein the backlight control circuit is further configured to:

receive a normalization value for the first outmost zone; and

calculate a normalized sum by dividing the sum of the values of the filtered pixel data by the normalization value, and

wherein controlling the luminance level of the first outmost light source is based on the normalized sum.

8. The display device of claim **7**, wherein the normalization value corresponds to a total sum of the filter coefficients determined for the first pixels and the second pixels.

9. The display device of claim **1**, wherein each of the plurality of zones is substantially rectangular.

10. The display device of claim **9**, wherein a horizontal width of the first outmost zone is different from a horizontal width of the inner zones, and/or a vertical height of the first outmost zone is different from a vertical height of the inner zones.

11. A display driver, comprising:

a driver circuit configured to drive a plurality of pixels located in a display area of a display panel, the display area being illuminated by a backlight device comprising an array of light sources, wherein the display area is segmented into a plurality of zones corresponding to the light sources, respectively, the plurality of zones comprising:

inner zones corresponding to inner light sources of the array of light sources, wherein the inner zones are located apart from edges of the display area of the display panel, and wherein each of the inner light sources is located at a center of a respective inner zone; and

outmost zones located along the edges of the display area of the display panel and corresponding to outmost light sources of the array of light sources, wherein each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone; and

a backlight control circuit configured to control a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels, the first pixels being located in a first outmost zone of the outmost zones, the first outmost light source corresponding to the first outmost zone.

12. The display driver of claim **11**, wherein the first outmost zone is defined to be an overlapping area of an extended zone and the display area of the display panel, and

wherein the extended zone is defined such that the extended zone has the same size and shape as a first inner zone of the inner zones and that the first outmost light source is located at the center of the extended zone, and

wherein the first inner zone is adjacent to the first outmost zone.

13. The display driver of claim **12**, wherein the backlight control circuit is further configured to:

receive an initialization value corresponding to a position of a corner of the first outmost zone in the extended zone;

determine, based on the initialization value, filter coefficients for the first pixels located in the first outmost zone; and

apply the determined filter coefficients to the first pixel data of the first pixels located in the first outmost zone to generate filtered pixel data of the first pixels, and

wherein controlling the luminance level of the first outmost light source is based on the filtered pixel data of the first pixels.

14. The display driver of claim **13**, further comprising a storage configured to store the initialization value.

15. The display driver of claim **12**, wherein controlling the luminance level of the first outmost light source is further based on second pixel data of second pixels of the plurality of pixels, the second pixels being located in adjacent zones of the plurality of zones, the adjacent zones being adjacent to the first outmost zone.

16. The display driver of claim **15**, wherein the backlight control circuit is further configured to:

receive an initialization value corresponding to a position of a corner of the first outmost zone in the extended zone:

determine, based on the initialization value, filter coefficients for the first pixels located in the first outmost zone and the second pixels located in the adjacent zones; and

apply the determined filter coefficients to the first pixel data of the first pixels and the second pixel data of the second pixels to generate filtered pixel data of the first pixels and the second pixels, and

wherein controlling the luminance level of the first outmost light source is based on the filtered pixel data of the first pixels and the second pixels.

17. The display driver of claim **16**, wherein the backlight control circuit is further configured to determine a sum of values of the filtered pixel data of the first pixels and the second pixels, and

wherein controlling the luminance level of the first outmost light source is based on the sum of the values of the filtered pixel data.

18. The display driver of claim **17**, wherein the backlight control circuit is further configured to:

receive a normalization value for the first outmost zone; and

calculate a normalized sum by dividing the sum of the values of the filtered pixel data by the normalization value, and

wherein controlling the luminance level of the first outmost light source is based on the normalized sum.

19. A method, comprising:

illuminating a display area of a display panel by a backlight device comprising an array of light sources, wherein the display area is segmented into a plurality of zones corresponding to the light sources, respectively, the plurality of zones comprising:

inner zones corresponding to inner light sources of the array of light sources, wherein the inner zones are located apart from edges of the display area of the display panel, and wherein each of the inner light sources is located at a center of a respective inner zone; and

outmost zones located along the edges of the display area of the display panel and corresponding to outmost light sources of the array of light sources, wherein each of the outmost zones is different in size or shape from at least one inner zone which is adjacent to at least one outmost zone;

driving a plurality of pixels located in the display area; and controlling a luminance level of a first outmost light source of the array of light sources based on first pixel data of first pixels of the plurality of pixels, the first pixels being located in a first outmost zone of the outmost zones, the first outmost light source corresponding to the first outmost zone.

20. The method of claim **19**, wherein the first outmost zone is defined to be an overlapping area of an extended zone and the display area of the display panel, and

wherein the extended zone is defined such that the extended zone has the same size and shape as a first inner zone of the inner zones and that the first outmost light source is located at the center of the extended zone, and

wherein the first inner zone is adjacent to the first outmost zone.

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