A display panel for use with a multi-panel display. The display panel includes a display panel including an array of display pixels disposed surrounded by a bezel, the array of display pixels for emitting a display image having a first size, and an optical expansion layer disposed over the array of display pixels to magnify the display image to appear to have a second size larger than the first size and to at least partially conceal the bezel surrounding the housing. The optical expansion layer includes a first array of microlenses optically coupled to the array of display pixels to cause light from the display pixels to diverge, a second array of microlenses having complementary optical power to the first array of microlenses; and an optically transparent offset layer disposed between the first and second arrays of microlenses. Other embodiments are disclosed and claimed.
SEAMLESS DISPLAY PANEL TILING USING AN OPTICAL EXPANSION LAYER

CROSS-REFERENCE TO RELATED APPLICATIONS


TECHNICAL FIELD

[0002] The present invention relates generally to displays and in particular, but not exclusively, to seamless display panel tiling using an optical expansion layer.

BACKGROUND

[0003] Large wall displays can be prohibitively expensive because the cost to manufacture display panels increases exponentially with display area. This cost increase arises from the increased complexity of large monolithic displays, the decreased yields associated with large displays (a greater number of components must be defect free for large displays), and increased shipping, delivery, and setup costs. Tiling smaller display panels to form larger multi-panel displays can help reduce many of the costs associated with large monolithic displays.

[0004] Figs. 1A-1B illustrate how tiling multiple smaller, less expensive display panels 100 together can achieve a large multi-panel display 105 that can be used as a large wall display. The individual images displayed by each display panel 100 can constitute a sub-portion of the larger overall composite image collectively displayed by multi-panel display 105. Multi-panel display 105 can reduce costs, but visually it has a major drawback. Each display panel 100 includes a bezel 110 around its periphery that houses pixel region 115 in which the display pixels are disposed. Manufacturers have recently reduced the thickness of bezel 110 considerably, to less than 2 mm, but even these thin bezels are very noticeable to the naked eye, meaning that they distract the viewer and otherwise detract from the overall visual experience.
Various other approaches for obtaining seamless displays include display lensing, blended projection, stackable display cubes, and LED tiles. Display lensing places a single contiguous lens in front of each display panel 100 to present a fused, borderless image in a particular "sweet spot." However, the viewing angle is relative narrow and image distortion along continuous lines still occurs. Blended projection uses software stitching and mechanical mounting of traditional projection screens. Currently, blended projection uses relatively low cost hardware and is a good option for non-planar surfaces. However, there are significant physical constraints on usage and installation and requires regular maintenance and sophisticated calibration. Stackable display cubes are a rear projection technology. Each display cube is relatively deep and the seams between adjacent cubes are easily visible. LED tiles are arrays of discrete RGB light emitting diodes ("LED"). LED tiles can have virtually invisible seams because the seams run between pixels. However, LED tiles are expensive and have large pixel pitches (e.g., 2 to 4 mm) that result in low resolution images.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the present invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

Figs. 1A-1B illustrate an embodiment of a display panel and an embodiment of display panel tiling.

Figs. 2A-2B together illustrate an embodiment of a display panel using an optical expansion layer.

Figs. 3A-3B are a cross-sectional view and a plan view, respectively, of an embodiment of a tiled display using display panels such as the one shown in Figs. 2A-2B.

Figs. 4A-4E are cross-sectional views of embodiments of optical expansion layers.

Figs. 5A-5C are cross-sectional views illustrating an embodiment of a process for making a display panel assembly.
Figs. 6A-6B are cross-sectional views illustrating alternative embodiments of processes for making a display panel assembly.

Figs. 7A-7B illustrate embodiments of communication protocols for displaying a composite image across multiple tiles of a multi-panel display.

Figs. 8A-8C illustrate embodiments of techniques for implementing intelligent reformatting/reconfiguration of a display image when an individual display tile is added to or removed from a multi-panel display.

Fig. 9 illustrates an embodiment of a process for image registration to cure misalignments between connected display tiles of a multi-panel display.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Embodiments are described of an apparatus, system, and method for seamless display panel tiling using an optical expansion layer. Numerous specific details are described to provide a thorough understanding of embodiments of the invention, but one skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In some instances, well-known structures, materials, or operations are not shown or described in detail but are nonetheless encompassed within the scope of the invention.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one described embodiment. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in this specification do not necessarily all refer to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

Figs. 2A-2B together illustrate an embodiment of a display panel 200; Fig. 2A is an exploded view, Fig. 2B an assembled view. Display panel 200 includes a display 203 and an optical expansion layer 215 that, when mounted over display 203, can conceal seams between display panels when display panel 200 is tiled with similar display panels into a tiled multi-panel display as shown in Fig. 3B. In the illustrated
embodiment, display 203 includes a pixel region 205 of lateral dimension W1 surrounded at least partially by a bezel 210.

[0019] In the illustrated embodiment, optical expansion layer 215 has a lateral dimension W2 substantially equal to the sum of dimension W1 and the width of bezel 210. Optical expansion layer 215 includes an offset layer 230 of thickness d. A first array of microlenses 220 is formed in or on one surface of offset layer 230, and a second array of complementary microlenses 225 is formed in or on the opposite surface of offset layer 230 spaced apart from each other by substantially distance d, such that individual microlenses in each array have a corresponding microlens in the other array positioned along coincident optical axis 237. In the embodiment shown, microlenses 220 and 225 are illustrated as refractive lenses, but in other embodiments other elements having optical power can be used, for example diffractive or reflective optical elements. Offset layer thickness d can depend on a variety of factors including, for example, the focal lengths of the individual microlenses in the first array of microlenses 220 and the second array of microlenses 225.

[0020] In the illustrated embodiment, when optical expansion layer 215 is positioned on display 203 the first array of microlenses 220 matches the array of display pixels 235 on a one-to-one basis; that is, each display pixel 235 is paired with a corresponding individual microlens 220. Each individual microlens 220 then magnifies the output from its corresponding display pixel 235. In magnifying the output from its corresponding pixel 235, each individual microlens 220 causes light from the pixel to diverge. Magnifying the pixel images using microlenses 220 and 225 serves to virtually displace the overall display image back to a virtual image plane 220 behind the actual image source plane 245, the result of which is that the bezel 210 is obscured.

[0021] Microlenses 225 are complementary to microlenses 220, meaning that their optical power is matched to the optical power of microlenses 220 to obtain the desired overall magnification and field of view for the user. In the illustrated embodiment, microlenses 225 further magnify the images from microlenses 220. Magnification by microlenses 225 further expands the display image to have a greater actual and/or apparent lateral extent W3 at the top surface of optical expansion layer 215 than the lateral extent W1 of pixel region 205. As such, the expanded image conceals
bezel 210. In this manner, when multiple display panels 200 are tiled into a tiled multi-panel display 300 (see., e.g., Figs. 3A-3B), the inter-panel seams are concealed.

[0022] In the illustrated embodiment, both display 203 and the optical expansion layer 215 are planar and rigid, but in other embodiments both the display panel and the optical expansion layer need not be planar or rigid, but can instead be curved and/or flexible. For example, in one embodiment display panel 203 and expansion layer 215 could both be both flexible and curved, so that a plurality of display panels 200 can be tiled onto a curved surface. In another embodiment, both display 203 and optical expansion layer 215 can be rigid and curved and can also be tiled to form a curved display.

[0023] Figs. 3A-3B together illustrate an embodiment of a tiled multi-panel display 300 including display panels such as display panel 200. Figure 3A is a cross-section, Fig. 3B a plan view. Tiled multi-panel display 300 includes four display panels 200 tiled together, such that each display panel 200 abuts two other display panels along its edge. Display panels 200 are joined such that bezel 210 of each display panel abuts the corresponding bezels of two other display panels 200. In the arrangement shown, the seams created by the abutting bezels 210 in the tiled multi-panel display would ordinarily be visible, but because display panels 200 include optical expansion layer's 215, the image output by the pixels in each display panel 200 masks the presence of the bezel such that they become invisible to the user. Other embodiments of tiled multi-panel display 300 can, of course, include lesser or greater number of display panels than shown.

[0024] Figs. 4A-4E illustrate other embodiments of optical expansion layers. Fig. 4A illustrates an embodiment of an optical expansion layer 400. Optical expansion layer 400 is similar in most respects to optical expansion layer 215. The primary difference is that in optical expansion layer 400 the optical axes of microlenses 404 in the first microlens array are not coincident with the optical axes of microlenses 406 in the second array of microlenses. Instead, the optical axes of individual microlenses 404 in the first microlens array are laterally shifted from the optical axes of the microlenses 406 in the second array by a distance $\delta$, such that each first microlens 404 is now optically coupled to one or more second microlenses 406. These microlens arrays can be engineered to have irregular patterns and/or direct light between microlenses 404 and 406.
along oblique paths. For example, lower microlenses 404 can be configured to direct light to laterally offset upper microlenses 406, as opposed to the microlens 406 directly above a given microlens 404. In other embodiments, the mapping of light from the lower array to the upper array can be randomized or pseudo-randomized to achieve a pixel randomization effect. Correspondingly, the size and layout spacing of first microlens array 404 and second microlens array 406 can be irregular.

[0025] Fig. 4B illustrates an embodiment of an optical expansion layer 420. Optical expansion layer 420 is in most respects similar to optical expansion layer 215: it includes a first array of microlenses 404 and a second array of microlenses 422, separated by a offset layer 402. Optical expansion layer 420 retains the one-to-one correspondence between microlenses 404 in first microlens array and the underlying pixels. The primary difference is that each microlens 422 in the second microlens array is optically coupled to more than one microlens 404 from the first microlens array, so that in optical expansion layer 420 there is a one-to-many correspondence between microlenses in the second microlens array and microlenses in the first microlens array. This is in contrast to optical expansion layer 215, in which there is a one-to-one correspondence between microlenses in the first and second microlens arrays.

[0026]Fig. 4C illustrates an embodiment of an optical expansion layer 440. Optical expansion layer 440 is in most respects similar optical expansion layer 215; it includes an array of first microlenses 442 optically coupled to an array of second microlenses 444 separated by a offset layer 402. The primary difference is that in optical expansion layer 440 each microlens 442 in the first microlens array is optically coupled to more than one pixel in the underlying pixel array, and is also optically coupled to more than one microlens from second microlens array 444. The result is that there is a many-to-one correspondence between pixels in the display and microlenses in the first microlens array, as well as a one-to-many correspondence between microlenses 442 in the first microlens array and microlenses 444 in the second microlens array. This differs from optical expansion layer 215, which has a one-to-one correspondence between microlenses in the first microlens array and the underlying pixels, as well as a one-to-one correspondence between microlenses in the first microlens array and microlenses in the second microlens array. In an alternative embodiment of optical expansion layer 440,
there could still be a one-to-one correspondence between microlenses in the first microlens array 442 and the underlying pixels while still having a one-to-many correspondence between microlenses 442 in the first microlens array and microlenses 444 in the second microlens array.

[0027] Fig. 4D illustrates an embodiment of an optical expansion layer 460. Optical expansion layer 460 is in most respects similar to optical expansion layer 215: it includes an array of first microlenses 220 and an array of second microlenses 225 separated by an offset layer 230. The primary difference is that in optical expansion layer 460 microlenses 462 and 464 closest to the edge of the optical expansion layer are angled outward to further help conceal the bezel when the optical expansion layer is mounted on the display panel and/or used in a tiled multi-panel display. In the illustrated embodiment only the microlenses closest to the edge—that is, microlens 462 in the first microlens array and microlens 464 in the second microlens array—are angled, but in other embodiments additional microlenses near the edge could be angled. For example, in each microlens array the two, three, or more microlenses closest to the edge could be angled. In the illustrated embodiment, both lenses in the edge lens pair are angled—that is, both edge microlens 462 from the first microlens array and edge microlens 464 from the second microlens array are angled—but in other embodiments only one of the two need be angled.

[0028] Fig. 4E illustrates an embodiment of an optical expansion layer 480. Optical expansion layer 480 is in most respects similar to optical expansion layer 215: it includes an array of first microlenses 220 and an array of second microlenses 225, separated by an offset layer 230. The primary difference is that optical expansion layer 480 includes mechanisms that can translate and/or rotate the microlenses in the first microlens array and the second microlens array. This would allow active concealment of seams between display panels. In one embodiment, the mechanisms to translate and/or rotate the microlenses can be micro-electro-mechanical-system (MEMS) micro-stage, but in other embodiments other kinds of mechanisms can be used. In the illustrated embodiment both the first array of microlenses 220 and the second array of microlenses 225 have all microlenses coupled to the movement mechanisms, but in other embodiments only the lenses in one microlens array need to be movable. In still other
embodiments, less than all of the microlenses within each microlens array need be movable.

[0029] Figs. 5A-5B illustrate an embodiment of a process for making a display panel. The illustrated process uses display panel 200 as an example, but a similar process can be used for display panels including any other optical expansion layer described. In the illustrated process, the parts that form the optical expansion layer are individually assembled onto the display panel with which the optical expansion layer will be used. Fig. 5A illustrates a first part of the process in which individual microlenses from the first array of microlenses 220 are formed on the display, thus forming an individual microlens 220 over each pixel in the display. Microlenses 220 in the first microlens array can be formed of any optically transparent material. Examples of materials that can be used include glass, polycarbonate, optically transparent high-index plastics such as CR39, optical grade acrylic, etc.

[0030] Fig. 5B illustrates a next part of the process. Having formed first array of microlenses 220 on the pixels in display 203, offset layer 230 is formed over first microlens array 220. Offset layer 230 can be formed using any of the materials used for first microlens array 220, but it might be necessary to use a different material than the material used for microlenses 220 in the first microlens array to ensure optical refraction at the interface between the individual microlenses and offset layer 230.

[0031] Fig. 5C illustrates a final part of the process. When the first microlens array and offset layer 230 have been formed on display 203, the array of second microlenses 225 can be formed on top of offset layer 230. Microlenses 225 in the second microlens array can be made of all the same materials of which lenses in the first microlens array can be made, and/or of which offset layer 230 is made. In one embodiment, microlenses 225 in the second microlens array can be made of the same material as the offset layer, but in other embodiments it need not be. In the illustrated embodiment, both display 203 and the optical expansion layer 215 are planar and rigid, but in other embodiments both the display panel and the optical expansion layer need not be planar or rigid, but can instead be curved and/or flexible. For example, in one embodiment display 203 and expansion layer 215 could both be both flexible and curved.
so that the resulting display panels 200 can be tiled to obtain a curved multi-panel display.

[0032] Figs. 6A-6B illustrate alternative embodiments of processes for making a display panel in which the optical expansion layer can be separately formed beforehand and then attached to the display, for example with fasteners or optically compatible adhesives. Fig. 6A illustrates an embodiment 600 in which optical expansion layer 215 is formed using its component parts—the array of first microlenses 225, the offset layer 230, and the array of second microlenses 225—and then attached to display panel 203. Optical extension expansion 215 can be made by molding the individual pieces together or forming the individual components separately and gluing them together.

[0033] Fig. 6B illustrates an alternative embodiment of a process for making a display panel using on optical expansion layer 652 that is formed substantially of a single piece that can then be attached to display panel 203. In one embodiment, the array of first microlenses 654 and offset layer 230 are formed of a single piece. In the illustrated embodiment, the first microlens array 654 is formed in one surface of offset layer 230 by forming voids in the surface, such that the microlenses in the first microlens array are essentially formed by the void itself and/or by a gas or vacuum in the void, and the microlenses gain their optical power from refraction at the gas/material interface between the void and offset layer 230. The second array of microlenses can also be molded directly into the opposite surface of offset layer 230 or, alternatively, the individual microlenses 225 of the second array of microlenses can be made separately and attached to the opposite surface of offset layer 230 opposite the first array of microlenses 654 using means such as optically compatible adhesives. Once finished, optical expansion layer 652 can then be attached to display panel 203.

[0034] Figs. 7A-7B illustrate embodiments of communication protocols for displaying a composite image across multiple display panels of a tiled multi-panel display 701. Display panels 700 in tiled multi-panel display 701 can be display panels that use any of the optical expansion layers described herein. Fig. 7A illustrates a technique where one display panel 700 operates as a master and the remaining display panels 700 operate as slaves that communicate with the master. The master device can be identical to the other slave devices, but merely designated as a master during
operation. For example, the master device can be the first display panel 700 logically added to the multi-panel display 701. As new display panels 700 are added or existing display panels 700 removed, the master display panel 700 can be responsible tracking and assigning display statuses and roles. In another embodiment, the master device can include additional interface electronics (e.g., wireless transceiver) not included in the other slave display panels 700 for communicating with a control device 705. The control device 705 can communicate display images and control information with the master display panel 700, which then relays the appropriate portions of the display images to the respective slave display panels 700. Fig. 7B illustrates a more distributed protocol where all display panels 700 are identical and operate as slave devices controlled directly by control device 705. Various registration markers can be used to identify and distinguish the various display panels 700. For example, magnetic bits, RFID, optical markers, active links, or various bus interfaces and signaling protocols can be used.

[0035] The illustrated embodiment of control device 705 includes a camera 710, an image engine 715, and registration logic 720. In one embodiment, control device 705 can be implemented with a smart phone having a general purpose processor, a built-in camera, and wireless interface electronics (e.g., WiFi or Bluetooth transceivers). The wireless interface electronics can be used to stream the composite image to display panels 700. Operation of control device 705 to set up and configure multi-panel displays 701 or 702 is discussed in further detail in connection with Fig. 9.

[0036] Figs. 8A-8C illustrate embodiments of techniques for implementing intelligent reformatting/reconfiguration of a display image when an individual display tile is added or removed from a multi-panel display 800. Display panels in tiled multi-panel display 800 can be display panels that use any of the optical expansion layers described herein. When panels are added to or removed from multi-panel display 800, the remaining display panels 801 can be intelligently reconfigured to effectively use the resulting display area. Intelligent reconfiguration can include adjusting image resolution or switching between a complex display interface for large composite display areas, and a simplified display interface for small composite displays (i.e., when the display area rises above or drops below a threshold size).
[0037] Figs. 8B-8C illustrate configuration options when the addition or removal of a display panel 801 results in an irregularly-shaped display area. In Fig. 8B, the display panel 801A forming the irregular shape is unused and the display image reverts to the largest available rectangular shaped area 810. In Fig. 8C, display panel 801A is used and the display image follows the irregular shaped area 815.

[0038] Fig. 9 illustrates an embodiment of a process 900 for image registration to cure misalignments between display tiles of a multi-panel display. Process 900 is described with reference to Fig. 7A. The order in which some or all of the process blocks appear in process 900 should not be deemed limiting. Rather, one of ordinary skill in the art having the benefit of the present disclosure will understand that some of the process blocks can be executed in a variety of orders not illustrated, or even in parallel.

[0039] When coupling two or more display panels 700 together, perfect physical alignment cannot be achieved, or the display panel can include intentionally randomized pixels that do not perfectly align. Process 900 identifies misalignments or image discontinuities along the seams of a tiled multi-panel display (or within an interior region of the display panel) and remaps display pixel to image pixel assignments to cure the defects.

[0040] In a process block 905, two or more display panels 700 are coupled together to form a tiled multi-panel display 701. As previously stated, this coupling can result in one or more image discontinuities along the inter-panel seams. To cure these defects, image engine 715 generates an initial registration image i (e.g., i = 1) for transmission to display panels 700. In one embodiment, registration image i is an alternating high contrast image (e.g., black and white checkerboard image) that provides several identifiable marks along the seam edges of each display panel 700 or displays a full screen image that provides enough information to recover the full position and orientation of each panel relative to one another.

[0041] In a process block 915, camera 710 is used to capture registration image i output from multi-panel display 701. The captured registration image i is then analyzed by registration logic 720 to identify any misalignment between panels (process block 920). If the misalignment is determined to be unacceptable (decision block 925), then registration logic 720 adjusts the display pixel to image pixel mapping in an attempt to
cure the discontinuities or at least reduce the number of image discontinuities. With the pixel assignments remapped, process 900 loops back to process block 910 and can iterate by redisplaying a revised registration image i. The registration iterations can continue until the alignment is determined to be within acceptable limits (decision block 925), at which time multi-panel display 701 is ready for use. Alternatively, this software alignment can be computed from a single calibration image. The remapped display pixel to image pixel assignments are maintained and used for all image feeds until the next recalibration cycle.

[0042] In some embodiments, the image registration technique described for Fig. 9 can further be used to smooth out other image discontinuities between the tiled panels than just physical misalignment of the display panels and their fibers. For example, the image registration technique can be used to adjust brightness, color temperature, etc. between the display panels to achieve uniform image characteristics and avoid perceived image characteristic boundaries between the tiled panels. Feedback from the displayed registration images can be used to adjust and smooth these differences. The image registration technique can even be used to smooth differences between individual pixels within a given display panel, if the underlying display permits such pixel-to-pixel adjustments.

[0043] The processes explained above are described in terms of computer software and hardware. The techniques described can constitute machine-executable instructions embodied within a tangible or non-transitory machine (e.g., computer) readable storage medium, that when executed by a machine will cause the machine to perform the operations described. A tangible machine-readable storage medium includes any mechanism that provides (i.e., stores) information in a form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). For example, a machine-readable storage medium includes recordable/non-recordable media (e.g., read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, flash memory devices, etc.). Additionally, the processes can be embodied within hardware, such as an application specific integrated circuit ("ASIC") or otherwise.
The above description of illustrated embodiments of the invention, including what is described in the abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. These modifications can be made to the invention in light of the above detailed description.

The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.
CLAIMS

1. A display panel for use with a multi-panel display, the display panel comprising:
   a display panel including an array of display pixels disposed surrounded by a bezel, the array of display pixels for emitting a display image having a first size; and
   an optical expansion layer disposed over the array of display pixels to magnify the display image to have a second size that appears larger than the first size and that at least partially conceals the bezel surrounding the housing, wherein the optical expansion layer includes:
       a first array of microlenses optically coupled to the array of display pixels to cause light from the display pixels to diverge;
       a second array of microlenses having complementary optical power to the first array of microlenses; and
       an optically transparent offset layer disposed between the first and second arrays of microlenses.

2. The display panel of claim 1 wherein there is a one-to-one correspondence between optical elements of the first array an optical elements in the second array.

3. The display panel of claim 1 wherein optical elements in the first array are substantially optically aligned with their corresponding optical element in the second array.

4. The display panel of claim 1 wherein the second array of microlenses are laterally offset relative to the first array of microlenses.

5. The display panel of claim 4 wherein the second array of microlenses has an irregular layout pattern to reduce an appearance of seams between adjacent display panels when the display panel is included in the multi-panel display.

6. The display panel of claim 1 wherein there is a one-to-many correspondence between optical elements of the second array and optical elements in the first array.
7. The display panel of claim 1 wherein the optical elements of the first array cause light received from one or more pixels to diverge such that the light exiting the optical elements appears to originate from an image plane behind their array of display pixels.

8. The display panel of claim 1 wherein the optical elements of the first array and the optical elements in the second array can be randomized to have a regular pattern, such that light is directed between optical elements in the first array an optical elements of the second array along oblique optical paths.

9. The display panel of claim 1 wherein the offset layer, the first array, and the second array are formed as a single piece.

10. The display panel of claim 9 wherein the microlenses of the first array are formed as voids in one surface of the offset layer.

11. The display panel of claim 9 wherein the single piece is adhered to the array of display pixels.

12. The display panel of claim 1 wherein the display panel and the optical expansion layers are both non-planar.

13. The display panel of claim 1 wherein one or both of the display panel and the optical expansion layer are flexible.

14. The display panel of claim 1 wherein microlenses in the first and second arrays closest to the edges of the optical expansion layer are tilted.

15. The display of claim 1, further including a mechanism to translate, rotate, or both rotate and translate the microlenses in the first array, the microlenses in the second array, or the microlenses in both the first array and the second array.

16. A tiled multi-panel display comprising a plurality of display panels tiled together along at least one edge of each display panel, each display panel comprising:
   
   an array of display pixels disposed surrounded by a bezel, the array of display pixels for emitting a display image having a first size; and

   an optical expansion layer disposed over the array of display pixels to magnify the display image to have a second size that appears larger than the first
size and that at least partially conceals the bezel surrounding the housing, wherein the optical expansion layer includes:

- a first array of microlenses optically coupled to the array of display pixels to cause light from the display pixels to diverge;
- a second array of microlenses having complementary optical power to the first array of microlenses; and
- an optically transparent offset layer disposed between the first and second arrays of microlenses.

17. The multi-panel display of claim 16 wherein in at least one display panel optical elements in the first array are substantially optically aligned with their corresponding optical element in the second array.

18. The multi-panel display of claim 16 wherein in at least one display panel the second array of microlenses are laterally offset relative to the first array of microlenses.

19. The multi-panel display of claim 18 wherein in at least one display panel the second array of microlenses has an irregular layout pattern to reduce an appearance of seams between adjacent display panels.

20. The multi-panel display of claim 16 wherein in at least one display panel the optical elements of the first array cause light received from one or more pixels to diverge such that the light exiting the optical elements appears to originate from an image plane behind their array of display pixels.

21. The multi-panel display of claim 16 wherein in at least one display panel the optical elements of the first array and the optical elements in the second array can be randomized to have a regular pattern, such that light is directed between optical elements in the first array an optical elements of the second array along oblique optical paths.

22. The multi-panel display of claim 16 wherein in at least one display panel the offset layer, the first array, and the second array are formed as a single piece.

23. The multi-panel display of claim 16 wherein each display panel is non-planar.
24. The multi-panel display of claim 16 wherein the display panels are flexible.

25. The multi-panel display of claim 16 wherein in at least one display panel microlenses in the first and second arrays closest to the edges of the optical expansion layer are tilted.

26. The multi-panel display of claim 16, wherein at least one display panel further includes a mechanism to translate, rotate, or both rotate and translate the microlenses in the first array, the microlenses in the second array, or the microlenses in both the first array and the second array.
CONNECT MULTIPLE DISPLAY PANELS INTO TILED MULTI-PANEL DISPLAY

DISPLAY REGISTRATION IMAGE (i)

CAPTURE REGISTRATION IMAGE (i) WITH CAMERA

ANALYZE REGISTRATION IMAGE (i) FOR IMAGE DISCONTINUITIES ALONG INTER-PANEL SEAMS

(i = i + 1)

DISCONTINUITIES ACCEPTABLE?

YES
MULTI-PANEL DISPLAY READY FOR USE (APPLY MAPPING ALGORITHM TO IMAGE FEEDS)

NO
REMAP DISPLAY PIXEL TO IMAGE PIXEL ASSIGNMENTS

FIG. 9
A. CLASSIFICATION OF SUBJECT MATTER

G09F 9/00(2006.01)i, G09G 3/20(2006.01)i, G09F 9/33(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G09F 9/00; H05B 33/14; H01I 63/04; G02F 1/133; G02F 1/1333; G09G 3/20; G09F 9/33

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: seamless, display, microlens, array, offset layer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
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<tbody>
<tr>
<td>X</td>
<td>US 2002-0080302 AI (MATTHEW B. DUBIN et al.) 27 June 2002 [0021] - [0032]; and figures 1, 2.</td>
<td>1-26</td>
</tr>
<tr>
<td>A</td>
<td>wo 98-43131 AI (RAINBOW DISPLAYS, INC.) 01 October 1998 page 7, line 10 - page 19, line 8; and figures 1-14.</td>
<td>1-26</td>
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<tr>
<td>A</td>
<td>US 2003-0071566 AI (ROBERT F. WASTNICK et al.) 17 April 2003 [0013] - [0026]; and figures 1-5.</td>
<td>1-26</td>
</tr>
<tr>
<td>A</td>
<td>wo 02-01284 AI (GL DISPLAYS, INC.) 03 January 2002 page 8, line 9 - page 22, line 3; and figures 3a-12.</td>
<td>1-26</td>
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Further documents are listed in the continuation of Box C.

See patent family annex.

Date of mailing of the international search report

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