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(72) Inventor; and

(71) Applicant: KHAN, Sajjad, Ali [US/US]; 978 Leith Ave,
Santa Clara, CA 95054 (US).

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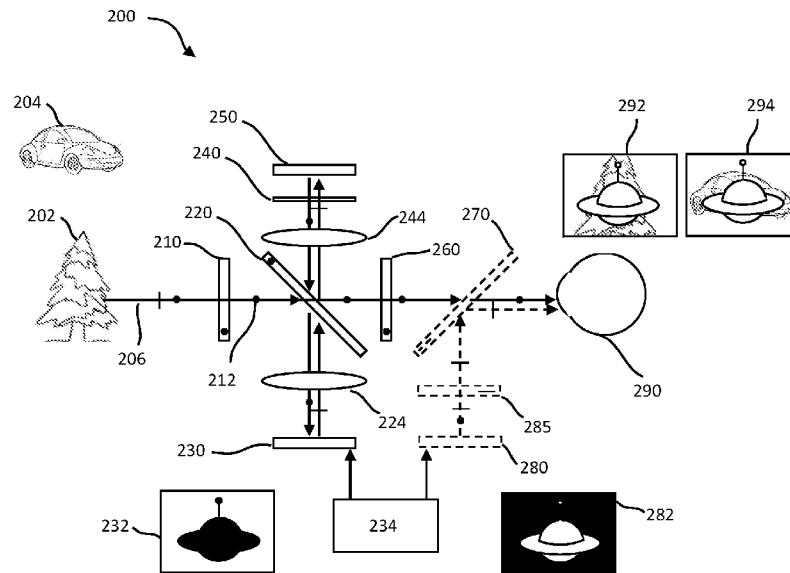


Figure 2.

(57) Abstract: In one embodiment, a method of rendering images includes providing eyewear having at least one lens. A display module routes image from an ambient real world environment first through a spatial light modulator so that selective portions of the real world scene can be occluded. The resultant image is then combined with another computer generated virtual image and then routed to the viewer. In another embodiment an electrically actuated switchable occlusion mechanism is provided within the display module that allows the ability to provide the occlusion capability only when needed.



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Claims

What is claimed:

1. An electronic display apparatus, comprising:
 - a controller;
 - at least one polarization based optical combiner, OC, located in the line of sight of the observer, and in close proximity of the observer's eye; said OC having a plurality of ports and comprising:
 - an absorptive linear polarizer, LP, having a transmission axis, T_{LP} ; said LP located on a first port of said OC facing the real world scene;
 - at least one reflective polarizer, RP, with a reflection polarization axis, R_{RP} , that is substantially parallel to T_{LP} ;
 - at least one spatial light modulator, SLM, located on a second port of said OC; said SLM comprising:
 - a plurality of pixels; whereby each pixel can modulate light; and said SLM being connected to said controller;
 - at least one powered optical element, S1, located along the light path between said LP and said SLM;
 - a Quarter Wave Plate, QWP, whose slow axis is located at approximately 45 degrees from T_{LP} ;
 - and a Mirror;
- wherein said QWP and said Mirror are located at a third port of said OC; wherein said third port is located opposing said second port of OC;

at least one powered optical element, S2, located along the light path between said RP and said mirror in third port of said OC;

wherein said LP polarizes the incoming light from the real world scene from said first port of OC in a preferred linear orientation along its transmission axis, T_{LP} ; wherein said RP is oriented at an angle such that it reflects the incoming polarized light from said LP in first port to said second port;

wherein said powered optical element, S1, forms an image of the real world scene at said SLM for modulation purposes;

wherein said SLM modulates the incoming polarized light from said second port and in turn provides outgoing modulated light in at least one of two states of linear polarizations; wherein said modulated light outgoing from said SLM is reflected back at said second port of the OC; wherein one of the modulated light states of linear polarization from said second port is substantially perpendicularly polarized to R_{RP} and hence it transmits from RP and emerges at said third port;

wherein said powered optical element, S2, relays the exit pupil at the Eyebox located in the said fourth port of OC; said fourth port located opposing said first port;

wherein said QWP and Mirror combination in said third port of OC operate on the light and reflect it back at the third port of OC but this time the light is linearly polarized parallel to R_{RP} ; wherein said RP reflects this light and routes it to said fourth port; wherein the light emerges at said exit pupil in said fourth port of OC for the observer's viewing thus allowing a see-through view to the observer;

wherein another of the modulated light states of linear polarization emerging from said SLM is substantially parallel polarized to R_{RP} and hence it reflects from RP and emerges at said first port hence exiting the OC towards the real world scene; wherein

such routing of light away from the viewer's eye gives the perception of pixel-wise selective blocking of see-through view to the observer.

2. The electronic display apparatus defined in claim 1, includes:
 - a Microdisplay, MD meant for creating digital virtual image content;
 - a second reflective polarizer, RP2, with a reflection polarization axis, R_{RP2} , that is substantially perpendicular to T_{LP} and also R_{RP} ; said RP2 is oriented at an angle such that it reflects the incoming polarized light from said MD to said fourth port;
 - at least one powered optical element, S3, located between said MD and said second reflective polarizer, RP2, such that an exit pupil is formed for MD image at said fourth port of OC that is co-located with said exit pupil of real world scene thereby overlaying the SLM modulated real world scene with MD created digital virtual content in the Eyebox for the observer's viewing.
3. The electronic display apparatus defined in claim 1, where the SLM is chosen from amongst one of the following: Liquid Crystal on Silicon, Micro Electro Mechanical Systems, Digital Light Processing, or Digital Micromirror Device.
4. The electronic display apparatus defined in claim 2, where the MD is chosen from amongst one of the following: Liquid Crystal on Silicon, Micro Electro Mechanical Systems (MEMS), Digital Light Processing, or Digital Micromirror Device, Micro Organic Light Emitting Diode, Micro Light Emitting Diode, or Micro Electro Mechanical Systems Resonant Scanning Mirror.
5. The electronic display apparatus defined in claim 2, where another Linear Polarizer, is included between the two said reflective polarizer, RP, and RP2, for cleanup purposes to mitigate any unwanted light leakage from either the see-through path or the SLM path.

6. The electronic display apparatus defined in claim 1, includes means to adjust the optical path length between said powered optical element, S1, and said SLM so that a different depth location in the real world scene can be brought into focus and occluded properly; such means may be either translation such as mechanical, or electro-mechanical; or tunable focus optical elements.
7. The electronic display apparatus defined in claim 1, where the powered optical element, S1, maybe either refractive, reflective, diffractive or holographic.
8. The electronic display apparatus defined in claim 1, where the powered optical element, S1, resides on the same substrate as the Reflective Polarizer, RP.
9. The electronic display apparatus defined in claim 2, where the two Reflective Polarizers, RP and RP2, are co-located in a single cubic space where they cross each other diagonally.
10. The electronic display apparatus defined in claim 9, where at least one of the two Reflective Polarizers, RP and RP2, has a cut running along its diagonal whereas the other Reflective Polarizer slides through said cut.
11. The electronic display apparatus defined in claim 10, where at least one of the two Reflective Polarizers, RP and RP2, is cut into two substantially parallel pieces along its diagonal.
12. The electronic display apparatus defined in claims 1 and 2, where RP and/or RP2 are chosen from amongst at least one of the following: Wire Grid Polarizer, Multilayer Optical Films, Notch Reflective Polarizers, Bragg Reflective Polarizers, Volume Phase Gratings, Holographic Gratings, Volume multiplexed Holographic Gratings, Angle multiplexed Holographic Gratings, Polarization multiplexed Holographic Gratings, Liquid Crystal Gratings, Polymerized Liquid Crystal Gratings, MacNeille type thin film coated cube.

13. The electronic display apparatus defined in claim 2, wherein at least one of said Reflective Polarizers, RP and RP2, is curved such that it additionally functions as said powered optical element S1 or S2 or S3.
14. The electronic display apparatus defined in claim 1, where the apparatus is a see-through Head Mounted Display.
15. The electronic display apparatus defined in claim 1, where at least one of the powered optical elements is a variable focus optic.
16. The electronic display apparatus defined in claim 2, includes means to adjust the optical path length between said Microdisplay, MD, and said powered optical element, S3, such that virtual objects projected into the eye box appear to be at varied depth location in the real world scene from the observer such as near or far.
17. The electronic display apparatus defined in claim 1, where rotational means are provided such as mechanical, or electro-mechanical; or beam steering optical to rotate the Reflective Polarizer, RP, such that a different portion of the real world scene, maybe occluded by the SLM.
18. The electronic display apparatus defined in claim 17, where said rotational means are connected to the observer's gaze direction.
19. The electronic display apparatus defined in claim 1, includes at least one Switchable Polarization Rotator; said Polarization Rotator capable of switching the linear polarization input light into one of two output linear polarization states at the command from the Controller; wherein one of said linear polarization states bypasses the SLM and substantially transmits through said Reflective Polarizers and emerges at the Eyebow in said fourth port of OC; wherein a second of said linear polarization states is substantially parallel to , T_{LP} , such that this light is reflected by RP and routed towards said SLM in said second port of OC.

20. The electronic display apparatus defined in claim 1, includes a reflective polarizer, and a camera; wherein said reflective polarizer is located preceding the absorptive linear polarizer, closer to the real world scene, such that it reflects at least one linear polarization of light from the real world scene towards said camera.
21. The electronic display apparatus defined in claim 1, includes at least one Quarter Wave Plate, QWP, located preceding the absorptive linear polarizer, LP, on said first port of OC, closer to the real world scene; wherein said QWP has its slow axis oriented at substantially 45 degrees from the transmission axis, T_{LP} , of LP, such that it randomizes the polarization of light incident from the real world scene on said apparatus.
22. The electronic display apparatus defined in claim 1, includes an Augmenting SLM and a partially transparent see through combiner based on a waveguide; wherein said waveguide is located in said fourth port of OC.
23. An electronic display apparatus, comprising:
- a controller;
 - a first lens array located facing the real world scene; said lens array meant to convert light from angular domain to spatial domain;
 - at least one spatial light modulator, SLM, comprising an array of pixels; whereby each pixel can modulate light; and said SLM being connected to said controller;
 - wherein said SLM is located a first distance, D_1 , away from said first lens array;
 - a 2nd lens array located near the observer's eye; said lens array meant to convert light back from spatial domain to angular domain; wherein said 2nd lens array is located a first distance, D_2 , away from said SLM;
 - wherein said controller commands said SLM to modulate light from selected pixels of said SLM such that the observer perceives the objects at corresponding angular

locations in the real world scene to be pixel-wise selectively blocked or modulated in their visible intensity from their view.

24. The electronic display apparatus in claim 23, wherein said distances, D1 and D2 between said first and second lens arrays and said SLM are equal to the focal length of the individual lenslets in the array.
25. The electronic display apparatus defined in claim 23, includes means to dynamically adjust the optical path distance, D1, between said SLM and said first lens array such that real objects at varied depth locations in the real world scene from the observer such as near or far can be blocked or attenuated from the observer's view properly.
26. The electronic display apparatus defined in claim 24, wherein said means for optical path distance adjustment are chosen from amongst one of the following: mechanical, electrical, Piezo-electric, electronic, optical, electro-optical, or opto-mechanical.
27. The electronic display apparatus defined in claim 23, where the SLM is chosen from amongst one of the following: Transmissive Liquid Crystal Display, Transmissive MEMS shutter array, Twist Nematic Liquid Crystal, Super Twist Nematic Liquid Crystal, Vertically Aligned Liquid Crystal, Parallel Rubbed Liquid Crystal, Anti-Parallel Rubbed Liquid Crystal, pi-cell Liquid Crystal, Ferro-electric Liquid Crystal, Polymer Dispersed Liquid Crystal, Polymer Stabilized Liquid Crystal, or Polymer Network Liquid Crystal.
28. The electronic display apparatus in claim 23, includes at least one absorptive linear polarizer, LP1, located facing the real world scene; wherein said LP1 is meant to polarize the lightfield incident on it from the real world scene.
29. The electronic display apparatus in claim 28, includes at least a 2nd absorptive linear polarizer, LP2, located facing the Eyebow, wherein the polarization transmission axes

of said LP1 and LP2 pair are either substantially parallel or substantially perpendicular to one another.

30. The electronic display apparatus defined in claim 29, a reflective polarizer, RP, is incorporated on the outside casing of the display such that the polarization reflection axis of said RP is orthogonal to the first linear polarizer's transmission axis utilized for the display.
31. The electronic display apparatus defined in claim 23, includes an array of baffles to prevent light leaking from one lenslet into a neighboring pixel of said SLM and control over directionality.
32. The electronic display apparatus defined in claim 23, wherein said SLM has a plurality of different pixel sizes such that real world objects of various angular dimensions can be occluded or attenuated depending upon their angular location within the FOV.
33. The electronic display apparatus defined in claim 31, wherein said SLM has fine pixel resolution in the center of the FOV and gradually coarser pixel resolution in the periphery of the FOV.
34. The electronic display apparatus defined in claim 23, includes an Augmenting SLM and a partially transparent see through combiner based on a waveguide; wherein said waveguide is located in said fourth port of OC.
35. An electronic display apparatus, comprising:
 - a controller;
 - at least two planar waveguides located between the real world scene and the observer's eye; each of said planar waveguides having a pair of in-coupling and out-coupling gratings;

at least one spatial light modulator, SLM, comprising an array of pixels; whereby each pixel can modulate light; and said SLM being connected to said controller;

at least one lens;

and at least one Mirror;

wherein said SLM is located between a first out-coupling grating of the first planar waveguide and said lens;

wherein lightfield from the real world scene routes through the first planar waveguide, in-coupling and out-coupling gratings to said SLM; wherein said lens forms a spatial image of the real world scene on said SLM; whereupon said controller commands said SLM to attenuate light from selected pixels of said SLM; whereupon said modulated image light reflects from said Mirror, and encounters said 2nd planar waveguide, the 2nd pair of in-coupling and out-coupling gratings and emerges in the Eyebow such that observer perceives the objects at corresponding angular locations in the real world scene to be pixel-wise selectively blocked or modulated in their visible intensity from their view.

36. The electronic display apparatus defined in claim 35, includes at least a pair of linear polarizers, and a Quarter Wave Plate, QWP, whose slow axis is located at approximately 45 degrees from the transmission polarization axis of one of said polarizers; wherein said QWP is location in front of said Mirror.

37. The electronic display apparatus defined in claim 35, where the SLM is chosen from amongst one of the following: Liquid Crystal on Silicon, Micro Electro Mechanical Systems, Digital Light Processing, or Digital Micromirror Device.

38. The electronic display apparatus defined in claim 35, includes:

a Microdisplay, MD, meant for creating digital virtual image content; and

a 3rd planar waveguide;

wherein said 3rd planar waveguide combines the light from said SLM thereby overlaying the SLM modulated real world scene with MD created digital virtual content in the Eyebox for the observer's viewing.

39. The electronic display apparatus defined in claim 38, where the MD is chosen from amongst one of the following: Liquid Crystal on Silicon, Micro Electro Mechanical Systems (MEMS), Digital Light Processing, or Digital Micromirror Device, Micro Organic Light Emitting Diode, Micro Light Emitting Diode, or Micro Electro Mechanical Systems Resonant Scanning Mirror.
40. The electronic display apparatus defined in claim 1, where said SLM is able to modulate light incident on each pixel in their transparency in the range of 0% to 99%.
41. The electronic display apparatus defined in claim 23, where said SLM is able to modulate light incident on each pixel in their transparency in the range of 0% to 99%.
42. The electronic display apparatus defined in claim 35, where said SLM is able to modulate light incident on each pixel in their transparency in the range of 0% to 99%.
43. An electronic display apparatus, comprising:
- a controller;
 - at least one optical combiner element located between a real world scene and the observer's eye;
 - at least one spatial light modulator, SLM, comprising an array of pixels; whereby each pixel can modulate light; and said SLM being connected to said controller;
 - at least one curved optical surface;
- wherein said curved optical surface is located between said combiner and said SLM;
- wherein lightfield from the real world scene routes through said combiner and said curved optical surface thus forming a spatial image of the real world scene on said

SLM; whereupon said controller commands said SLM to modulate light from selected pixels of said SLM;

whereupon said SLM substantially selectively modulates light from selected pixels of the real world scene image into a plurality of output states; wherein at least a first of said output states is substantially transparent while a second output state is substantially opaque;

whereupon said selectively modulated lightfield is routed to an exit pupil for viewing by the observer's eye;

whereupon the observer's eye perceives the objects at corresponding angular locations in the real world scene to be selectively modulated in their visibility from his/her view.

44. The electronic display apparatus defined in claim 43, includes at least one pupil relaying mechanism; said pupil relaying mechanism located between the SLM and the observer's eye; and said pupil relaying mechanism being responsible for relaying the pupil of the modulated SLM image of the real world scene into the observer's eye.
45. The electronic display apparatus defined in claim 43, where the SLM is chosen from amongst one of the following: Liquid Crystal on Silicon, Micro Electro Mechanical Systems, Digital Light Processing, or Digital Micromirror Device.
46. The electronic display apparatus defined in claim 43, where the combiner is a freespace combiner.
47. The electronic display apparatus defined in claim 43, includes at least one linear polarizer, and a Quarter Wave Plate, QWP, whose slow axis is located at approximately 45 degrees from the transmission polarization axis of said linear polarizer; wherein said QWP is location in front of said Mirror.

48. The electronic display apparatus defined in claim 43, where the combiner is immersed in an optical medium.
49. The electronic display apparatus defined in claim 43, where the combiner is a waveguide combiner.
50. The electronic display apparatus defined in claim 43, includes a Microdisplay, MD, meant for creating digital virtual image content.
51. The electronic display apparatus defined in claim 50, includes a 2nd combiner for injecting digital virtual image content from said Microdisplay, MD, thereby overlaying the transparency modulated SLM image of the real world scene with MD created digital virtual content in the Eyebox for the observer's viewing, hence providing the observer with an image with high contrast and wide dynamic range.
52. The electronic display apparatus defined in claim 43, includes a camera located substantially near the observer's viewing point of the real world scene; said camera connected to said controller; whereby said camera provides the information about scene image such as lighting, lighting direction and orientation, saturation, intensity, illuminance, white point, dynamic range and similar to the controller; said controller determines which image pixels to selectively attenuate or dim down and conveys the same via a command to the SLM for corresponding SLM pixels to be selectively controlled to impact their visibility to the observer.
53. The electronic display apparatus defined in claim 43, where said plurality of output states range in their transparency in the range of 0% to 99%.
54. An electronic display apparatus, comprising:
a controller;
at least one spatial light modulator, SLM, comprising an array of pixels; whereby each pixel can modulate light; and said SLM being connected to said controller;

at least one image forming element;
wherein said electronic display apparatus is located between the lightfield emanating from a real world scene and an observer's eye;
wherein said image forming element converts said lightfield from said real world scene into a spatial image of the real world scene on said SLM and vice versa;
whereupon said controller commands said SLM to modulate light from selected pixels of said SLM;
whereupon said SLM substantially selectively modulates light from selected pixels of the real world scene image into a plurality of output states; wherein at least a first of said output states is substantially transparent while a second output state is substantially opaque;
whereupon said selectively modulated lightfield is routed to an exit pupil for viewing by the observer's eye;
whereupon the observer's eye perceives the objects at corresponding angular locations in the real world scene to be selectively modulated in their visibility from his/her view.

55. The electronic display apparatus defined in claim 54, where the SLM is substantially transmissive in nature.
56. The electronic display apparatus defined in claim 54, where the SLM is chosen from amongst one of the following: Liquid Crystal Display, High Temperature Poly-silicon based Liquid Crystal Display, Transflective Liquid Crystal Display, Parallel-Aligned Liquid Crystal Display, Anti-Parallel-Aligned Liquid Crystal Display, Twist Nematic Liquid Crystal Display, Super Twist Nematic Liquid Crystal Display, Vertically Aligned Liquid Crystal, Parallel Rubbed Liquid Crystal, Anti-Parallel Rubbed Liquid Crystal, pi-cell Liquid Crystal Display, Ferro-electric Liquid Crystal, Polymer

Dispersed Liquid Crystal, Polymer Stabilized Liquid Crystal, or Polymer Network Liquid Crystal, and Transmissive MEMS shutter array.

57. The electronic display apparatus defined in claim 54 where said at least one image forming element consists of at least one lens array.
58. The electronic display apparatus defined in claim 54 includes additional optical element to correct for image erectness and orientation.
59. The electronic display apparatus defined in claim 54, includes at least one pupil relaying mechanism; said pupil relaying mechanism located between the SLM and the observer's eye; wherein said pupil relaying mechanism relays the lightfield as modulated by said SLM into an exit pupil located at the observer's eye.
60. The electronic display apparatus defined in claim 54, includes at least one linear polarizer.
61. The electronic display apparatus defined in claim 54, includes at least one circular polarizer.
62. The electronic display apparatus defined in claim 60, includes at least one Quarter Wave Plate, QWP, whose slow axis is located at approximately 45 degrees from the transmission polarization axis of said linear polarizer.
63. The electronic display apparatus defined in claim 54, where the controller receives said command via a user interface.
64. The electronic display apparatus defined in claim 54, where said plurality of output states includes at least one semi-transparent state.
65. The electronic display apparatus defined in claim 54, where said plurality of output states range in their transparency in the range of 0% to 99%.