(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 May 2012 (03.05.2012)

PCT

(10) International Publication Number
WO 2012/057622 A1

(51) International Patent Classification:
H04N 5/232 (2006.01) *H04N 9/04* (2006.01) *H04N 5/225* (2006.01)

(21) International Application Number: PCT/NL2011/050725

(22) International Filing Date: 24 October 2011 (24.10.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/406,148 24 October 2010 (24.10.2010) US

(72) Inventors; and
(71) Applicants : **ATTAR, Ziv** [IL/IL]; 24 Inbar street POB 10149, IL-30900 Zihron Yaakov (IL). **AHARON-ATTAR, Chen** [IL/IL]; 24 Inbar street POB 10149, IL-30900 Zihron Yaakov (IL).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **WOLTERINK, Edwin Maria** [NL/NL]; Kromstraat 62, NL-5554 NH Valkenswaard (NL).

(74) Agent: **ALGEMEEN OCTROOI- EN MERKENBUREAU B.V.**; P.O. Box 645, NL-5600 AP Eindhoven (NL).

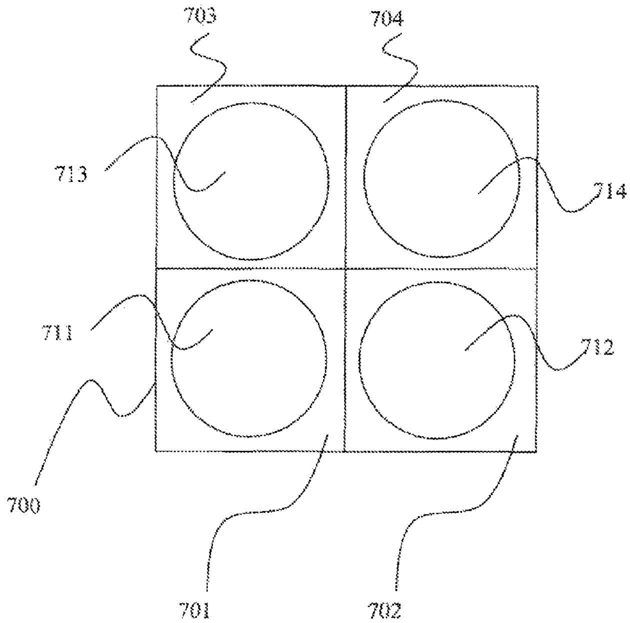
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR IMAGING USING MULTI APERTURE CAMERA

Figure 7



(57) Abstract: The present invention relates to as system and method for improving the spatial resolution of digital cameras that consist of multiple imaging lens assemblies (hereinafter: imaging channels) and at least one sensor that can be divided in to two or more regions. The imaging lenses are designed to have the same field of. The final processed image is composed of details obtained by different imaging channels. Each imaging channel provides luminance details for different areas of the final image while three or more imaging channels provide chrominance (color details) of the complete scene. As a result higher resolution, higher dynamic range and low light performance is achieved. The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced imaging systems having more than one aperture.

WO 2012/057622 A1

Published:

— *with international search report (Art. 21(3))*

SYSTEM AND METHOD FOR IMAGING USING MULTI APERTURE CAMERA

The present invention relates to as system and method for improving the spatial resolution of digital cameras that consist of multiple imaging lens assemblies (hereinafter: imaging channels) and at least one sensor that can be divided in to two or more regions. The imaging lenses are designed to have the same field of. The final processed image is composed of details obtained by different imaging channels. Each imaging channel provides luminance details for different areas of the final image while three or more imaging channels provide chrominance (color details) of the complete scene. As a result higher resolution, higher dynamic range and low light performance are achieved. The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced imaging systems having more than one aperture.

BACKGROUND OF THE INVENTION

US 2001/0134282 relates to an imaging device, comprising: a lens array including a plurality of lenses facing a subject; an image sensor obtaining a compound-eye image including single-eye images of the subject formed by the lenses; and a computing unit processing the compound-eye image obtained by the image sensor, wherein the lenses have different radii of curvature and substantially a same back focal length; and the computing unit extracts an in-focus image from the compound-eye image. The imaging unit also includes light-shielding walls for preventing crosstalk between light beams passing through adjacent lens sets of the lens array. The imaging unit also includes an image sensor such as a CMOS sensor that converts optical images of the subject formed by the lens sets of the lens array into an image signal (data), wherein the image sensor is mounted on a substrate. Lens surfaces of the lens sets of the lens array have different radii of curvature so that the lens sets focus at different subject distances. In addition to setting the radii of curvature as described above, the lens sets are configured to have substantially the same back focal length.

International application WO 2009/151903 relates to camera array fabricated on a semiconductor substrate to include a plurality of sensor elements, comprising: a first imager fabricated at a first location of the semiconductor substrate, the first imager including at least two first image sensor elements; and a second imager fabricated on a second location of the semiconductor substrate, the second imager including at least two second image sensor elements not overlapping with first image sensor elements. International application WO 2009/151903 relates to using a distributed approach to capturing images using a plurality of imagers of different imaging characteristics wherein each imager may be spatially shifted from another imager in such a manner that an imager captures an image that us shifted by a sub-pixel amount with respect to another imager captured by another imager. Each imager may also include separate optics with different filters and operate with different operating parameters (e.g., exposure time). Distinct images generated by the imagers are processed to obtain an enhanced image. Each imager may be associated with an optical element fabricated using wafer level optics (WLO) technology.

US 2011/0080487 relates to an imaging device comprising at least one imager array, and each imager in the array comprises a plurality of light sensing elements and a lens stack including at least one lens surface, where the lens stack is configured to form an image on the light sensing elements, wherein a spectral filter is provided within each imager and is configured to pass a specific spectral band of light; and spectral filters that pass different spectral bands are provided within at least two of the imagers. In addition, US 2011/0080487 also discloses that at least one lens surface in the optical stack of an imager differs based upon the specific spectral band of light passed by the spectral filter within the imager; and each lens surface is selected from the group consisting of diffractive, Fresnel, refractive and combinations thereof, wherein each of the imagers is optically separated from the other imagers by at least two opaque surfaces located in front of the light sensing elements and having openings arranged in axial alignment with the lens stack of the imager.

US 2005/0225654 relates to a color camera, including at least three sub-cameras, each sub-camera having an imaging lens, a color filter, and an array of detectors, wherein filters associated with a color set are substantially the same. The color camera combines images from the at least three sub-cameras to form a composite multi-color image, at least two of the at least three sub-cameras each generate an image for a substantially same color spectra, the at least two images for the substantially same color spectra having a variation there between to provide a resolution of a composite image for the substantially same color spectra which is higher than that of an individual sub-camera, a resolution of a color image not having the substantially same color spectra being less than the resolution of the composite image.

JP2011109484 relates to a multiple-lens camera apparatus with which several image area, the color filter of each color positioned for this every imaging region, and the lens array to which it corresponded for this every imaging region wherein the multiple-lens camera apparatus with which the focal distances with respect to this imaging region of at least two sub lenses of this lens array mutually differ.

An imaging system typically consists of an imaging lens and a detecting sensor. An imaging lens collects light emitted or reflected from objects in a scene and images this light onto a detector. A detector is a photosensitive device, which converts light in to electronic signal later forming a digital image. To photograph a color image a color filter must be used to separate between different spectral regions of the total spectrum that is being imaged.

A common filter that is used is called a Bayer mask which is a mask that is positioned on top of the detecting surface and allows different spectra (colors) to reach different pixels on the detector, for example a Bayer filter is composed of one green pixel mask followed by a red pixel mask followed on the row below by a blue pixel mask and finally another green pixel mask. Using a color mask such as a Bayer mask requires the use of a standard single lens having sufficient resolution and performance at all 3 colors used by the color mask (Red Green and Blue in the case of a Bayer mask but other color combinations can be used having different spectrum filters placed in different pixel location).

An object of the present invention is improve effective resolution, more preferably image spatial resolution.

Another object of the present invention is to provide improved low light performance by making smart use of the multiple imaging channels.

Another object of the present invention is to provide higher dynamic range of the final image.

The present invention relates generally to a system and method for capturing an image, and more particularly to an advanced system employing a multi aperture camera. More in detail the present invention relates to a system for improving image spatial resolution using a multi aperture digital camera having at least two imaging channels.

The term multi aperture digital camera as referred to means a camera that consists of more than one imaging lenses each having its aperture and lens elements. The term lenses of the different imaging channels as referred to means any imaging lens that may consist of one or more optical surfaces having an optical power that is different than zero. The term image spatial resolution as referred to means the ability of lens to create an image which can resolve details that have a size of 1/f in which f is the spatial resolution.

The present inventors found that the image spatial resolution can by improved by using a multi aperture camera as recited in the appended claims and sub claims. In an aspect of the disclosure there is provided a system for imaging including a one or more imaging sensors; two or more lenses, each lens forms an initial image at a different location on the sensor or on the different sensors in the case of multiple sensors. According to an embodiment at least two of the apertures have the same field of view of the different imaging channels.

The present inventors also found that the image dynamic range can be increase using an algorithm that combines the luminance of the different imaging channels

When using multi aperture digital cameras, each lens forms an image that is smaller than the size of the sensor or total size of sensors. The resulting products of such a multi aperture digital camera are multiple images that have lower effective resolution, lower than an image captured by a single aperture lens using the same sensor or a single sensor having a pixel count that is equal to the sum of the plurality of sensors. This reduction of resolution can be compensated by use of more pixels but this solution leads to higher price and larger dimensions, which is undesirable in most cases.

The following invention proposes a solution that allows increasing the effective resolution of a multi aperture camera.

SUMMARY OF THE INVENTION

In an imaging system containing multi apertures as described above we will address herein after each lens and the area of the sensor in which the lens forms an image on as an imaging channel.

The digital camera is composed of two or more imaging channels where the imaging lens of each channel can be different than the imaging lens of other channels. The focal length of a lens is defined by the distance in which the lens will form an image of an object that is positioned at infinity.

The lens F-Number is defined as the focal length divided by the entrance pupil diameter which is set by the lens aperture.

According to the present invention selecting the source of luminance from a plurality of images captured by a multi aperture digital camera wherein the selection is on the level of one or more pixels

The present invention relates to a system and method which may be applied to a variety of imaging systems. This system and method provide high quality imaging while considerably reducing the length of the camera as compared to other systems and methods.

Specifically, the object of the present invention is to provide a system and a method to improve image capturing devices while maintaining the same filed of view. This is accomplished by using a 2 or more lenses. Each lens forms a small image of the scene. Each lens transfers light emitted or reflected from objects in the scenery onto a proportional area in the detector. The optical track of each lens is proportional to the segment of the detector which the emitted or reflected light is projected on. Therefore, when using smaller lenses, the area of the detector which the emitted or reflected light is projected on, referred hereinafter as the active area of the detector, is smaller. When the detector is active for each lens separately, each initial image formed is significantly smaller as compare to using one lens which forms an entire image. One lens camera transfers emitter or reflected light onto the entire detector area.

Therefore instead of using a single lens to form a large image covering the complete sensor active area, we propose to use two or more lenses where each form a small image covering only a part of the sensor's active area. The sensor that will be used will not have any color mask on its active area and instead each lens will have a color filter integrated within the optical barrel or in front of the lens (between the lens and the scene) or between the lens and the sensor or placed on top of the sensor part that is used with the specific lens.

Thus the present invention relates to a system for selecting the source of luminance from a plurality of images captured by a multi aperture digital camera wherein the selection is on the level of one or more pixels. The advantage of such selecting is that image resolution, dynamic range and low light performance can be improved.

According to another embodiment the aforementioned selection is on level of one pixel. The advantage of selecting on the pixel level is that at borders of bright and dark areas the source of luminance will change as to allow maximal signal to noise ration in the dark areas and avoid saturation at the bright areas by choosing the imaging channel with the lowest signal values in the bright areas as a source of luminance.

According to another embodiment the aforementioned selection is on a level of a group of adjacent pixels. The advantage of selecting on the pixel group level is that computation time can be reduced.

According to another embodiment the pixels in the aforementioned group are identified as containing edges by an edge detection algorithm. The advantage of selecting pixel groups according to edges is that it can highly reduce computation time.

According to another embodiment the aforementioned system has two or more of the lenses of the multi aperture digital camera are focused at the same distance.
The advantage of having two or more imaging channels focus at the same distance is to achieve maximal image quality and effective resolution at a given distance.

According to another embodiment at least two of the imaging channels of the aforementioned multi aperture digital camera have the same field of view. The advantage of having same field of view on two or more of the imaging channels is to maximize the size of the image in which information is available on all imaging channels.

According to another embodiment at least one of the imaging channels includes a neutral density filter. The advantage of having a neutral density included in one or more of the imaging channels is to enable high dynamic range of the final image by selection of the source of luminance from the different imaging channels. When an imaging channel which does not include a neutral density filter is saturated another imaging channel that does include a neutral density filter might not be saturated due to the lower transmission caused by the neutral density filter.

According to another embodiment at least one of the aforementioned imaging channels includes a chromatic filter. The advantage of including a chromatic filter is the ability of the multi aperture camera to capture a color image.

According to another embodiment at least one of the aforementioned imaging channels includes a polarizing filter. The advantage of including such a filter is that reflection from smooth surface such as bodies of water, automobiles, windows and alike is reduced or removed.

According to another embodiment the aforementioned imaging channels form an image on a single imaging detector. The advantage of using a single detector is that it enables low cost and simplicity of assembly and operation.

According to another embodiment not all aforementioned imaging channels are exposed equally. The advantage of exposing different imaging channels differently is that we can control white balance in color images by applying different exposure durations to the different imaging channels, which include a chromatic filter. Another advantage exposing different imaging channels differently is the increase in the dynamic range of the final image.

According to another embodiment a system at least two of the aforementioned imaging channels include a chromatic filter and in which at least one additional imaging channel has a broader spectral transmission than the said chromatic filter. The advantage of the above system is that by choosing luminance from the broader spectral filtered channel in areas which are dark, and by selecting luminance at other areas from all imaging channels we are able to improve the low light performance of a camera. Another advantage of the above embodiment is to enable high dynamic range of the final image by selection of the source of luminance from the different imaging channels. When an imaging channel which includes a broader spectral filter is saturated another imaging channel that includes a chromatic filter might not be saturated. Choosing the source of luminance from imaging channels that are not saturated will lead to an increase of the dynamic range of the final image.

In addition the present invention relates to a method for composing a color image from a plurality of images captured by a multi aperture digital camera using the system as discussed here, which method comprises the following steps:

A. Comparing the signal values of the one or more pixels from the corresponding captured images of the different imaging channels.

B. Selecting the source of luminance for the one or more pixels in the final image from the different imaging channels according to comparison of step A.

C. Adjusting the signal values in said one or more pixels of step B.

D. Combining the thus adjusted one or more pixels into a composed luminance of the final image.

E. Selecting the source of chrominance from three or more imaging channels.

F. Combining the luminance of step D and chrominance of step E into a final color image.

According to another embodiment the present invention relates to a method for composing a monochrome image from a plurality of images captured by a multi aperture digital camera using the present system, which method comprises the following steps:

A1. Comparing the signal values of the one or more pixels from the corresponding captured images of the different imaging channels.

B1. Selecting the source of luminance for the one or more pixels in the final image from the different imaging channels according to comparison of step A1.

C1. Adjusting the signal values in said one or more pixels of step B1.

D1. Combining the thus adjusted one or more pixels into a composed final image.

The present invention relates to the use of the present system for improving image spatial resolution. In addition, the present invention relates to the use of the present system for improving image low light performance. Furthermore, the present invention relates to the use of the present system for improving image dynamic range.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a side view of a single lens camera.

Figure 2 illustrates a sensor array (201) having multiple pixels.

Figure 3 illustrates a side view of a three lens camera having one sensor and three lenses.

Figure 4 illustrates an example of a scene as projected on to the sensor.

Figure 5 illustrates a front view of a three lens camera using one rectangular sensor divided in to three regions.

Figure 6 illustrates a front view of a three lens camera having one sensor, one large lens and two smaller lenses.

Figure 7 illustrates a front view of a four lens camera having a one sensor (700) and four lenses.

Figure 8 illustrates a 16 lens camera having four regions, each containing four lenses as illustrated in figure 7.

Figure 9 illustrates an image of a small light source as appears on a sensor.

Figure 1 illustrates a side view of a single lens camera having a single lens (102) that can comprise one or more elements and a single sensor (101).

Figure 2 illustrates a sensor array (201) having multiple pixels where the position of the green filter, red filter and blue filter are marked by (202), (203) and (204) respectively. The image that will be taken using this configuration needs to be processed in order to separate the green, red and blue images.

Figure 3 illustrates a side view of a three lens camera having one sensor (310) and three lenses (301), (302) and (303). Each one of the said lens will project the image of the same scene on to segments of the sensor marked by (311), (312), and (313) respectively. Each one of the three lenses will have different color filters integrated within the lens, in front of it or between the lens and sensor (310).Using the described configuration the image acquired by the sensor will be composed of two or more smaller images, each imaging information from the scene at different spectrums.

Figure 4 illustrates an example of a scene as projected on to the sensor (401), in each region of the sensor (402), (403) and (404) the same scene is projected but each region will contain information for light at different wavelengths representing different colors according to the filters integrated within the lens that forms the image on each region.

The described configuration does not require the use of a color mask and therefore the maximal spatial frequency that can be resolved by the sensor is higher, on the other hand using smaller lens and smaller active area per channel necessarily means that the focal length of the lens is smaller and therefore the spatial resolution in objects space is decreased. Overall the maximal resolvable resolution for each color remains same.

The image acquired by the sensor is composed of two or smaller images, each containing information of the same scene but in different colors. The complete image is then processed and separated in to 3 or more smaller images and combined together to one large color image.

The described method of imaging has many advantages:

1. Shorter lens track (height) as each one of the lens used is smaller in size than the single lens covering the same field of view, the total track (height) of each lens is smaller allowing the camera to be smaller in height, an important factor for mobile phone cameras, notebook cameras and other applications requiring short optical track.
2. Reduced Color artifacts- Since each color is captured separately, artifacts originating from spatial dependency of each color in a color mask will not appear.
3. Lens requirements: each lens does not have to be optimal for all spectrums used but only for one spectrum, allowing simplifying the lens design and possibly decreasing the amount of elements used in each lens as no color correction is needed.
4. Larger Depth of Focus: the depth of focus of a system depends on its focal length. Since we use smaller lenses with smaller focal lengths, we increase the depth of focus by the scale factor squared.

5. Elimination of focus mechanism: focus mechanisms change the distance between the lens and the sensor to compensate for the change in object distance and to assure that the desired distance is in focus during the exposure time. Such a mechanism is costly and has many other disadvantages such as:
    a. Size
    b. Power consumption
    c. Shutter lag
    d. Reliability
    e. price

Using a fourth lens in addition to the three used for each color red, green and blue (or other colors) with a broad spectral transmission can allow extension of the sensor's dynamic range and improve the signal-to-noise performance of the camera in low light conditions.

All configuration described above using a fourth lens element can be applied on other configurations having two or more lenses.

Another configuration that is proposed is using two or more lenses with one sensor having a color mask integrated or on top of the sensor such as a Bayer mask. In such a configuration no color filter will be integrated in to each lens channel and all lenses will create a color image on the sensor region corresponding to the specific lens. The resulting image will be processed to form one large image combining the two or more color images that are projected on to the sensor.

Three lens camera:

Dividing the sensor's active area in to 3 areas, one for each color Red, Green and Blue (or other colors) can be achieved by placing 3 lens one beside the other as described in the drawing below: The resulting image will consist of 3 small images were each contains information of the same scene in different color. Such a configuration will comprise of 3 lenses where the focal length of each lens is 4/9 of an equivalent single lens camera that uses a color filter array, these values assume a 4:3 aspect ratio sensor.

Figure 5 illustrates a front view of a three lens camera using one rectangular sensor (500) divided in to three regions (501), (502) and (503). The three lenses (511), (512) and (513) each having different color filters integrated within the lens, in front of the lens or between the lens and the sensor are used to form an image of the same scene but in different colors. In This example each region of the sensor (501), (502) and

(503) are rectangular having the longer dimension of the rectangle perpendicular to the long dimension of the complete sensor.

Other three lens configuration can be used, such as using a larger green filtered lens and two smaller lenses for blue and red, such a configuration will results in higher spatial resolution in the green channel since more pixels are being used.

Figure 6 illustrates a front view of a three lens camera having one sensor (600), one large lens (613) and two smaller lenses (611) and (612). The large lens (613) is used to form an image on the sensor segment marked (603) while the two smaller lenses form an image on the sensor's segments marked with (601) and (602) respectively. The larger lens (613) can use a green color filter while the two smaller lenses (611) and (612) can use a blue and red filter respectively. Other color filters could be used for each lens.

Four lens camera:

A four lens camera will comprise of 4 lenses each having different color filter integrated within the lens, before the lens or between the lens and the sensor region corresponding to the said lens. The color filters use for each lens can be partially repeated meaning a specific color filter can appear twice causing 2 of the 4 lens to image the same scene and at the same spectrum.

Figure 7 illustrates a front view of a four lens camera having a one sensor (700) and four lenses (711), (712), (713) and (714). Each lens forms an image on the corresponding sensor region marked with (701), (702), (703) and (704) respectively. Each one of the lenses will be integrated with a color filter in side the lens, in front of the lens or between the lens and the sensor. All four lenses could be integrated with different color filter or alternatively two of the four lenses could have the same color filter integrated in side the lens, in front of the lens or between the lens and the sensor. For example using two green filters one blue filter and one red filter will allow more light collection in the green spectrum.

MxN lens camera:

Using M and /or N larger than 2 allows higher shortening factor and higher increase in depth of focus.

Figure 8 illustrates a 16 lens camera having 4 regions (801), (802), (803) and (804) each containing four lenses as illustrated in figure 7.

Figure 9 illustrates a an image of a small light source (901) as appears on the sensor (900) in two channels (910 and 920), in 910 the light source creates a signal in two neighboring pixels, the resulting signal of the left image channels is a blurred image of the small light source (901). In the right side of the sensor (920) the light source was imaged on to a single pixel. The resulting image of the light source will be sharper. Using both channels as sources of luminance and comparing the sharpness of each pixel or group of pixels on the different imaging channels followed by a selection of the source of luminance according to the sharpness found at the different images.

CLAIMS

1. A system for selecting the source of luminance from a plurality of images captured by a multi aperture digital camera wherein the selection is on the level of one or more pixels.

2. The system of claim 1 in which the selection is on level of one pixel.

3. The system in claim 1 in which the selection is on a level of a group of adjacent pixels.

4. The system in claim 3 in which the adjacent pixels within the aforementioned group are identified as containing edges by an edge detection algorithm.

5. A system of claim 1 in which two or more of the lenses of the multi aperture digital camera are focused at the same distance 15.

6. The system of claim 1 in which at least two of the imaging channels of the multi aperture digital camera have the same field of view.

7. The system of claim 1 in which at least one of the imaging channels includes a neutral density filter.

8. The system of claim 1 in which at least one of the imaging channels includes a chromatic filter.

9. The system of claim 1 in which at least one of the imaging channels includes a polarizing filter.

10. The system of claim 1 in which the imaging channels form an image on a single imaging detector.

11. The system of claim 1 in which not all imaging channels are exposed equally.

12. A system of claim 1 in which the at least two of the imaging channels include a chromatic filter and in which at least one additional imaging channel has a broader spectral transmission than the said chromatic filter.

13 A method forcomposing a color image from a plurality of images captured by a multi aperture digital camera using the system according to claims 1-12 in comprising the following steps:

A. Comparing the signal values of the one or more pixels from the corresponding captured images of the of different imaging channels.

B. Selecting the source of luminance for the one or more pixels in the final image from the different imaging channels according to comparison of step A.

C. Adjusting the signal values in said one or more pixels of step B.

D. Combining the thus adjusted one or more pixels into a composed luminance of the final image.

E. Selecting the source of chrominance from three or more imaging channels.

F. Combining the luminance of step D and chrominance of step E into a final color image.

14. A method forcomposing a monochrome image from a plurality of images captured by a multi aperture digital camera using the system according to claims 1-12 in comprising the following steps:

A1. Comparing the signal values of the one or more pixels from the corresponding captured images of the of different imaging channels.

B1. Selecting the source of luminance for the one or more pixels in the final image from the different imaging channels according to comparison of step A1.

C1. Adjusting the signal values in said one or more pixels of step B1.

D1. Combining the thus adjusted one or more pixels into a composed final image.

15. The use of a system according to any one of the claims 1-12 for improving image spatial resolution.

16. The use of a system according to any one of the claims 1-12 for improving image low light performance.

17. The use of a system according to any one of the claims 1-12 for improving image dynamic range.

Figure 1

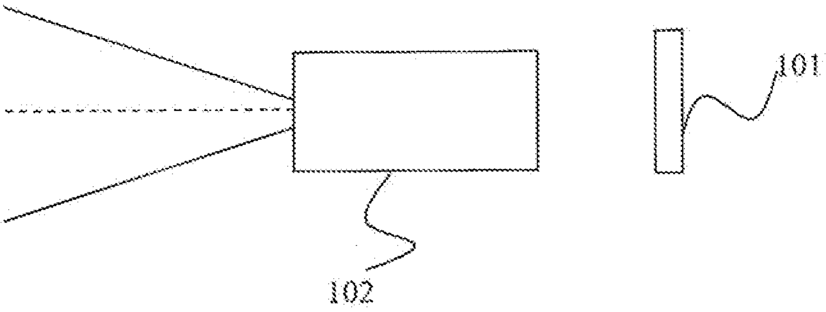


Figure 2

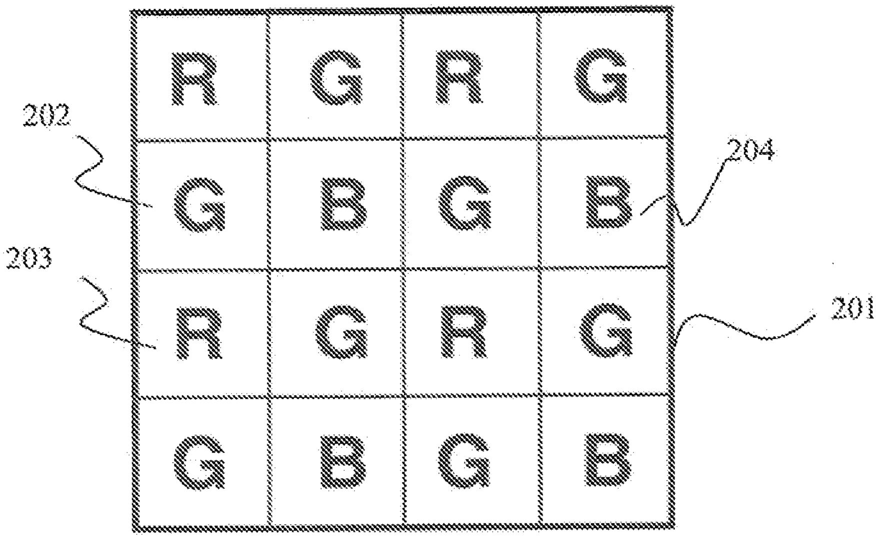


Figure 3

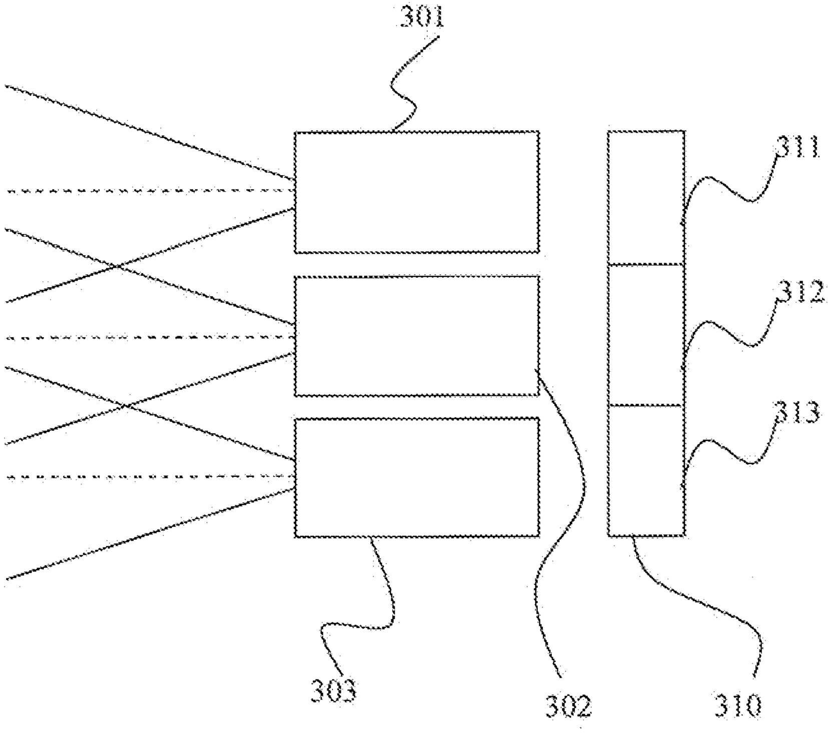


Figure 4

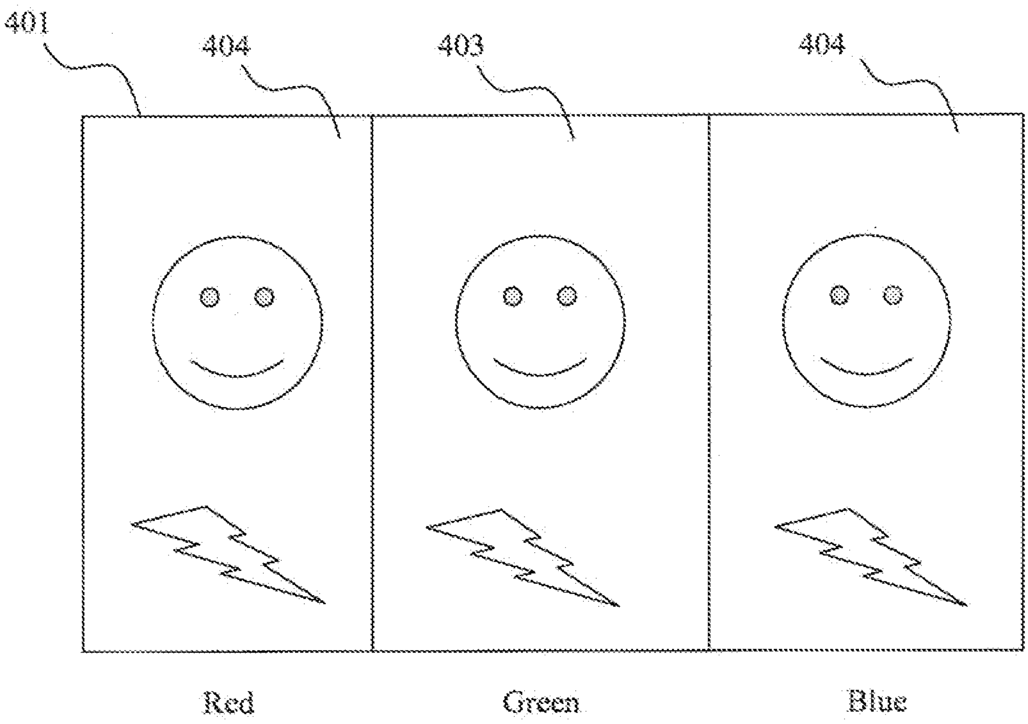


Figure 5

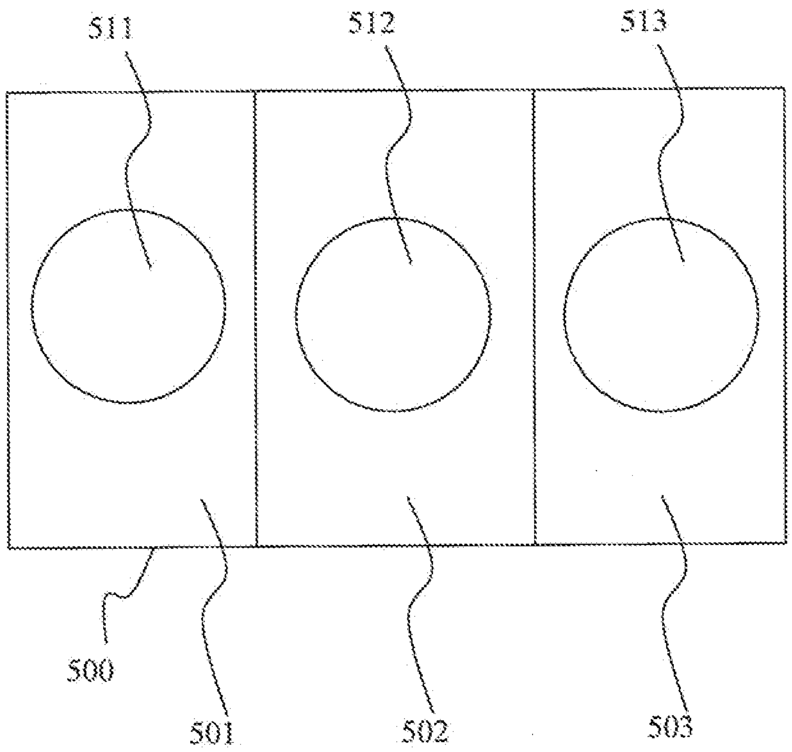


Figure 6

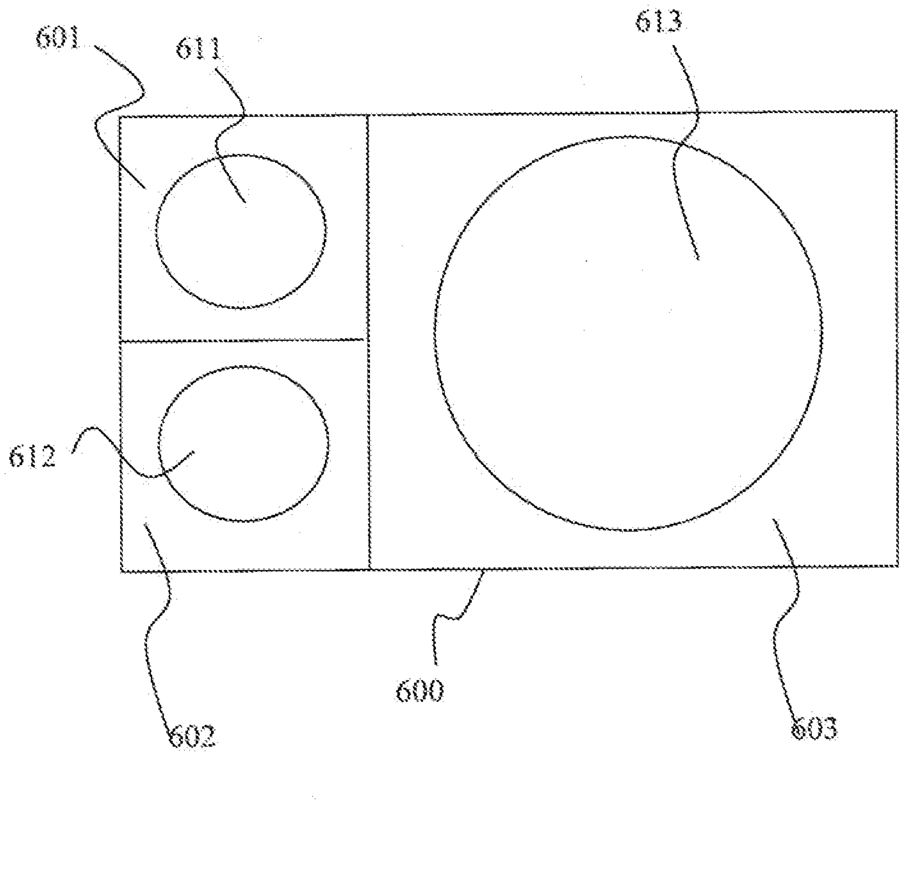


Figure 7

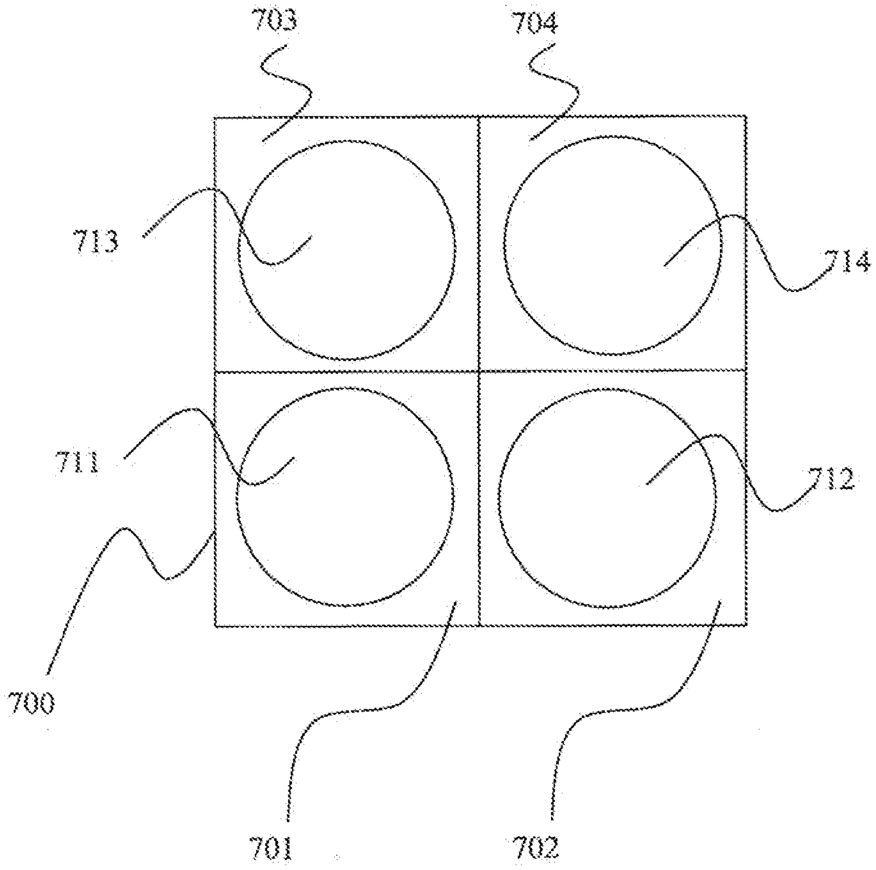


Figure 8

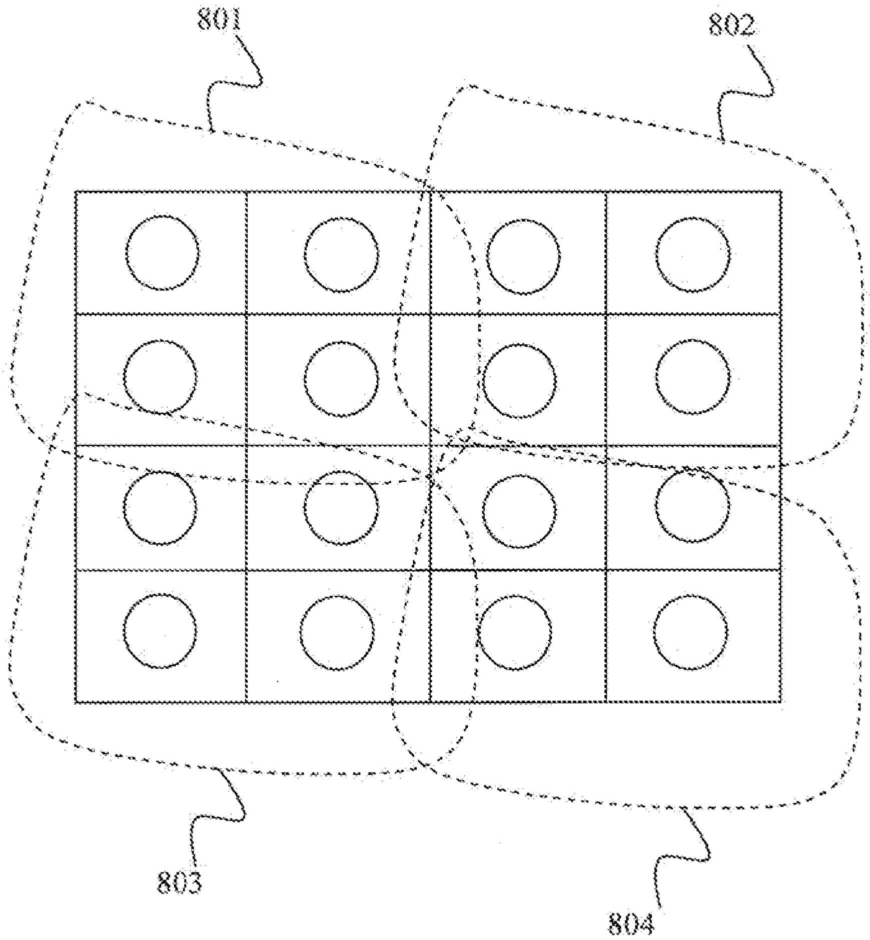
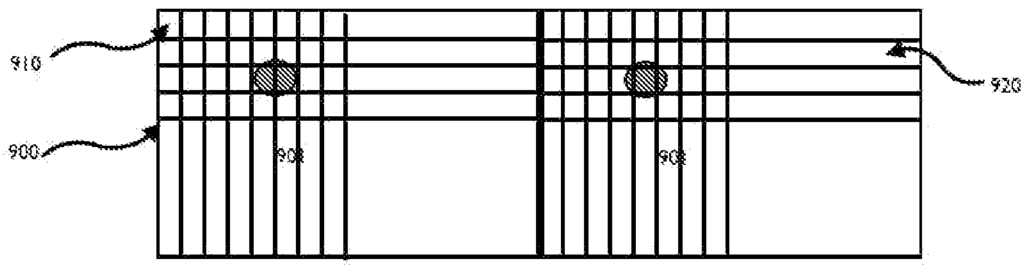


Figure 9



INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2011/050725

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N5/232 H04N5/225 H04N9/04
ADD.

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)
H04N G06K

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2007/177004 A1 (KOLEHMAINEN TIMO [FI] ET AL) 2 August 2007 (2007-08-02)	1-3,5,6, 8-12,16, 17
Y	paragraph [0020] - paragraph [0061] figures 1-5	4,7, 13-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 January 2012	01/02/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Potin, Delphine

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	M. MIROTZNIK ET AL: "A practical enhanced-resolution integrated optical-digital imaging camera (PERIODIC)", PROCEEDINGS OF SPIE, vol. 7348, 1 January 2009 (2009-01-01), pages 734806-734806-9, XP55015831, ISSN: 0277-786X, DOI: 10.1117/12.819484 paragraph [0001] - paragraph [0004] figures 1-7 -----	7,15
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