With a plurality of imagers, there is no such limit to the exposure time per sample because multiple imagers may be operated to capture images in a staggered manner.

[0054] Each imager can be operated independently. Entire or most operations associated with each individual imager may be individualized. In one embodiment, a master setting is programmed and deviation (i.e., offset or gain) from such master setting is configured for each imager. The deviations may reflect functions such as high dynamic range, gain settings, integration time settings, digital processing settings or combinations thereof. These deviations can be specified at a low level (e.g., deviation in the gain) or at a higher level (e.g., difference in the ISO number, which is then automatically translated to deltas for gain, integration time, or otherwise as specified by context/master control registers) for the particular camera array. By setting the master values and deviations from the master values, higher levels of control abstraction can be achieved to facilitate a simpler programming model for many operations. In one embodiment, the parameters for the imagers are arbitrarily fixed for a target application. In another embodiment, the parameters are configured to allow a high degree of flexibility and programmability.

[0055] In one embodiment, the camera array is designed as a drop-in replacement for existing camera image sensors used in cell phones and other mobile devices. For this purpose, the camera array may be designed to be physically compatible with conventional image sensors of approximately the same resolution although the achieved resolution of the camera array may exceed conventional image sensors in many photographic situations. Taking advantage of the increased performance, the camera array in accordance with embodiments of the invention may include fewer pixels to obtain equal or better quality images compared to conventional image sensors. Alternatively, the size of the pixels in the imager may be reduced compared to pixels in conventional image sensors while achieving comparable results.

[0056] In order to match the raw pixel count of a conventional image sensor without increasing silicon area, the logic overhead for the individual imagers is preferably constrained in the silicon area. In one embodiment, much of the pixel control logic is a single collection of functions common to all or most of the imagers with a smaller set of functions applicable to each imager. In this embodiment, the conventional external interface for the imager may be used because the data output does not increase significantly for the imagers.

[0057] In one embodiment, the camera array including the imagers replaces a conventional image sensor of M megapixels. The camera array includes $N \times N$ imagers, each sensor including pixels of $\frac{M}{N^2}$. Each imager in the camera array also has the same aspect ratio as the conventional image sensor being replaced. Table 1 lists example configurations of camera arrays according to the present invention replacing conventional image sensor.

Table 1

Conventional Image Sensor		Camera array Including Imagers					
Total Mpixels	Effective Resolution	Total Mpixels	No. of Horizontal Imagers	No. of Vertical Imagers	Imager Mpixels	Super-Resolution Factor	Effective Resolution
8	3.2	8	5	5	0.32	3.2	3.2
		8	4	4	0.50	2.6	3.2
		8	3	3	0.89	1.9	3.2
5	2.0	5	5	5	0.20	3.2	2.0
		5	4	4	0.31	2.6	2.0
		5	3	3	0.56	1.9	2.0
3	1.2	3	5	5	0.12	3.2	1.2
		3	4	4	0.19	2.6	1.2
		3	3	3	0.33	1.9	1.2

[0058] The Super-Resolution Factors in Table 1 are estimates and the Effective Resolution values may differ based on the actual Super-Resolution factors achieved by processing.

[0059] The number of imagers in the camera array may be determined based on, among other factors, (i) resolution, (ii) parallax, (iii) sensitivity, and (iv) dynamic range. A first factor for the size of imager is the resolution. From a resolution point of view, the preferred number of the imagers ranges from 2 x 2 to 6 x 6 because an array size of larger than 6 x 6 is likely to destroy frequency information that cannot be recreated by the super-resolution process. For example, 8 Megapixel resolution with 2 x 2 imager will require each imager to have 2 Megapixels. Similarly, 8 Megapixel resolution with a 5 x 5 array will require each imager to have 0.32 Megapixels. In many embodiments, the number of imagers in the array is determined based upon the requirements of a specific application.

[0060] A second factor that may constrain the number of imagers is the issue of parallax and occlusion. With respect to an object captured in an image, the portion of the background

scene that is occluded from the view of the imager can be referred to as the "occlusion set." When two imagers capture the object from two different locations, the occlusion set of each imager is different. Hence, there may be scene pixels captured by one imager but not the other. To resolve this issue of occlusion, it is desirable to include a certain minimal set of imagers for a given type of imager and to distribute the imagers symmetrically around the central axis of the camera array.

[0061] A third factor that may put a lower bound on the number of imagers is the issue of sensitivity in low light conditions. To improve low light sensitivity, imagers for detecting near-IR spectrum may be needed. The number of imagers in the camera array may need to be increased to accommodate such near-IR imagers.

[0062] A fourth factor in determining the size of the imager is dynamic range. To provide dynamic range in the camera array, it is advantageous to provide several imagers of the same filter type (chroma or luma). Each imager of the same filter type may then be operated with different exposures simultaneously. The images captured with different exposures may be processed to generate a high dynamic range image.

[0063] Based on these factors, the preferred number of imagers is 2 x 2 to 6 x 6. 4 x 4 and 5 x 5 configurations are more preferable than 2 x 2 and 3 x 3 configurations because the former are likely to provide sufficient number of imagers to resolve occlusion issues, increase sensitivity and increase the dynamic range. In addition, rectangular arrays can also be preferred. At the same time, the computational load required to recover resolution from these array sizes will be modest in comparison to that required in the 6x6 array. Arrays larger than 6 x 6 may, however, be used to provide additional features such as optical zooming and multispectral imaging. Although only square imagers are described here, as will be discussed in greater detail later, such imagers may have different x- and y-dimensions.

[0064] Another consideration is the number of imagers dedicated to luma sampling. By ensuring that the imagers in the array dedicated to near-IR sampling do not reduce the achieved resolution, the information from the near-IR images is added to the resolution captured by the luma imagers. For this purpose, at least 50% of the imagers may be used for sampling the luma and/or near-IR spectra. In one embodiment with 4 x 4 imagers, 4 imagers samples luma, 4 imagers samples near-IR, and the remaining 8 imagers sample two chroma (Red and Blue). In another embodiment with 5 x 5 imagers, 9 imagers sample luma, 8 imagers sample near-IR, and the remaining 8 imagers sample two chroma (Red and Blue).

Further, the imagers with these filters may be arranged symmetrically within the camera array to address occlusion due to parallax. In a further embodiment with 5 x 5 imager, 17 imagers sample luma, 4 images sample Red, and 4 imagers sample Blue.

[0065] In one embodiment, the imagers in the camera array are spatially separated from each other by a predetermined distance. By increasing the spatial separation, the parallax between the images captured by the imagers may be increased. The increased parallax is advantageous where more accurate distance information is important. Separation between two imagers may also be increased to approximate the separation of a pair of human eyes. By approximating the separation of human eyes, a realistic stereoscopic 3D image may be provided to present the resulting image on an appropriate 3D display device.

[0066] In one embodiment, multiple camera arrays are provided at different locations on a device to overcome space constraints. One camera array may be designed to fit within a restricted space while another camera array may be placed in another restricted space of the device. For example, if a total of 20 imagers are required but the available space allows only a camera array of 1 x 10 imagers to be provided on either side of a device, two camera arrays each including 10 imagers may be placed on available space at both sides of the device. Each camera array may be fabricated on a substrate and be secured to a motherboard or other parts of a device. In addition, such imagers do not have to be homogenous in size, and may have different x- and y-dimensions. The images collected from multiple camera arrays may be processed to generate images of desired resolution and performance.

[0067] A design for a single imager may be applied to different camera arrays each including other types of imagers. Other variables in the camera array such as spatial distances, color filters and combination with the same or other sensors may be modified to produce a camera array with differing imaging characteristics. In this way, a diverse mix of camera arrays may be produced while maintaining the benefits from economies of scale.

Wafer Level Optics Integration

[0068] In one embodiment, the camera array employs wafer level optics (WLO) technology. Although in many embodiments, similar optical channels can be constructed using any of a variety of techniques including but not limited to injection molding, glass molding, and/or combinations of these techniques with other techniques including WLO techniques. WLO itself is a technology that encompasses a number of processes, including,

for example, molding optics (such as arrays of lens modules and arrays of those lens arrays) on glass wafers, stacking of those wafers (including wafers having lenses replicated on either side of the substrate) with appropriate spacers, at either a wafer or die-level, followed by packaging of the optics directly with the imager into a monolithic integrated module.

[0069] The WLO procedure may involve, among other procedures, using a diamond-turned mold to create each polymer lens element on a glass substrate. More specifically, the process chain in WLO generally includes producing a diamond turned lens master (both on an individual and array level), then producing a negative mold for replication of that master (also called a stamp or tool), and then finally forming a polymer replica on a glass substrate, which has been structured with appropriate supporting optical elements, such as, for example, apertures, light blocking materials, filters, etc.

[0070] Figure 2A is a perspective view of a camera array assembly 200 with wafer level optics 210 and a sensor array 230, according to one embodiment. The wafer level optics 210 includes a plurality of lens elements 220, each lens element 220 covering one of twenty-five imagers 240 in the sensor array 230. Note that the camera array assembly 200 has an array of smaller lens elements occupy much less space compared to a single large lens covering the entire sensor array 230. It should also be noted that each of the lenses may be of a different type. For example, each substrate level may contain lenses that are diffractive, refractive, Fresnel, or a combination thereof. It should be further noted that in the context of the camera array, that a lens element 220 may comprise one or multiple separate optical lens elements axially arranged with respect to each another. Finally, it should be noted that, for most lens materials there will be a thermal induced variance in the refractive index of the material, which must be corrected to obtain good image quality. A temperature normalization procedure will be described in greater detail in the sections to follow. Figure 2B is a sectional view of a camera array assembly 250, according to one embodiment. The camera assembly 250 includes a top lens wafer 262, a bottom lens wafer 268, a substrate 278 with multiple sensors and associated light sensing elements formed thereon and spacers 258, 264 and 270. The camera array assembly 250 is packaged within an encapsulation 254. An optional top spacer 258 may be placed between the encapsulation 254 and the top lens wafer 262; however, it is not essential to the construction of the camera assembly 250. Optical elements 288 are formed on the top lens wafer 262. Although these optical elements 288 are shown as being identical in Figure 2B, it should be understood that different types, sizes, and

shapes of elements may be used. A middle spacer 264 is placed between the top lens wafer 262 and a bottom lens wafer 268. Another set of optical elements 286 is formed on the bottom lens wafer 268. A bottom spacer 270 is placed between the bottom lens wafer 268 and the substrate 278. Through-silicon vias 274 are also provided to paths for transmitting signal from the imagers. The top lens wafer 262 may be partially coated with light blocking materials 284 (see discussion below) to block of light. The portions of the top lens wafer 262 not coated with the blocking materials 284 serve as aperture stops through which light passes to the bottom lens wafer 268 and the light sensing elements. Although only a single aperture stop is shown in the embodiment provided in Figure 2B, it should be understood that additional aperture stops may be formed from opaque layers disposed on any and all of the substrate faces in the camera assembly to improve stray light performance and reduced optical crosstalk. A fuller discussion of optical crosstalk suppression is provided below. In addition, although the above embodiment is shown with spacers 258, 264 and 270 the spacer function can also be directly implemented by modifying the lens structures (or substrates) so that the lenses can be directly interconnected. In such an embodiment, the lens height can be extended, and the lens glued directly to the upper substrates thereby eliminating the need for spacer layers.

[0071] In the embodiment of Figure 2B, filters 282 are formed on the bottom lens wafer 268. Light blocking materials 280 may also be coated on the bottom lens 268 to function as an optical isolator. A light blocking material 280 may also be coated on the substrate 278 to protect the sensor electronics from incident radiation. Spacers 283 can also be placed between the bottom lens wafer 268 and the substrate 278 and between the lens wafers 262, 268. In many embodiments, the spacers 283 are similar to the spacers 264 and 270. In a number of embodiments, each layer of spacers is implemented using a single plate. Although not illustrated in FIG. 2B, many embodiments of the invention also include spacers between each optical channel located on top of the top lens wafer 262 that are similar to, or implemented in single layer with, the spacer 258 shown at the edge of the lens stack array. As is discussed further below the spacers can be constructed from and/or coated in light blocking materials to isolate the optical channels formed by the wafer level optics. For the purposes of this application, suitable light blocking materials may include any opaque material, such as, for example, a metal material like Ti and Cr, or an oxide of these materials like black chromium (chrome and chrome oxide), or dark silicon, or a black particle filled photoresist

like a black matrix polymer (PSK2000 from Brewer Science). The bottom surface of the substrate is covered with a backside redistribution layer ("RDL") and solder balls 276.In one embodiment, the camera array assembly 250 includes 5 x 5 array of imagers. The camera array 250 has a width W of 7.2mm, and a length of 8.6mm. Each imager in the camera array may have a width S of 1.4mm. The total height t1 of the optical components is approximately 1.26mm and the total height t2 the camera array assembly is less than 2mm. Other heights t1 and t2 are possible for different lens designs.

Optical Crosstalk Suppression

[0072] As discussed above, the camera array assembly 250 is composed of multiple imagers, each of which, as shown in Figures 2A and 2B, have a corresponding optical pathway or channel that directs light from the scene through the top lens wafer 262, the middle spacer 264, bottom lens wafer 268, the bottom spacer 270 and onto a plurality of light sensing elements that form a sensor 240 disposed on the substrate 278. It is important to final image quality that the light impinging on any particular imager come only from its designated optical pathway or channel. Optical crosstalk can be considered to occur when light that is incident on the top of one imager is also received by light sensing elements of another imager within the array. Any crosstalk between optical channels from, for example, diffraction and/or scattering of light from elements within the camera, can introduce artifacts in the image data. In particular, crosstalk between optical channels means that an imager will sense the flux from a source on the imager that is inconsistent with the reconstructed position of the image of that detector and the position of the image. This results in both a loss of image data, and the introduction of overlapping noise that cannot be distinguished from real image data. Accordingly, all optical channels of the camera array should be optically isolated so that a ray of light from one lens or optical channel cannot cross from one optical channel to the other. In one embodiment, shown in Figure 2C, opaque spacers 281 or vertical opaque walls 282 are disposed between each of the optical channels 284. Although opaque spacers do provide a level of optical crosstalk suppression, vertical opaque walls are preferable because in such an embodiment both the space between substrates and the relevant sections of the substrates themselves are rendered non-transparent.

[0073] The optical crosstalk suppressing vertical opaque walls may be made using any suitable technique that provides for the introduction of an opaque surface or material between

the optical channels 284 of the camera array assembly 286. In one embodiment, the vertical opaque walls are formed by fully or partially introducing grooves into the lens stack 288 of the camera array assembly 286. It is preferable not to cut the grooves fully through the lens stack to preserve the mechanical integrity of the camera array assembly. Such grooves may be introduced by any suitable technique, such as, for example, by dicing into the front or backside of the lens array stack 286 using a wafer dicer (disk/blade), or by laser cutting, or water-jet cutting. Once the grooves are formed, they are filled with a light blocking material. Alternatively, the inner side walls of the grooves may be coated with a light blocking material and the remainder of the groove filled with another material with low shrinkage properties. As discussed above, a light blocking material is any opaque material, such as, for example, a metal material, a metal oxide, dark silicon, or a black particle filled photoresist like a black matrix polymer.

[0074] In another embodiment, shown schematically in Figure 2D, optical crosstalk suppression is achieved by creating a virtual opaque wall formed by a series of stacked apertures. In this embodiment, a series of aperture stops are formed on the various substrate levels 290 of the camera array assembly 292 by coating the substrates with opaque layers 294 provided with a narrow opening or aperture 296. If enough of these apertures are formed, it is possible to mimic the optical isolation provided by a vertical opaque wall. In such a system, a vertical wall would be the mathematical limit of stacking apertures one on top of each other. Preferably, as many apertures as possible, separated from each other by sufficient space, are provided so that such a virtual opaque wall is created. For any camera array assembly, the number and placement of opaque layers needed to form such a virtual vertical opaque wall can be determined through a ray tracing analysis.

[0075] In a further embodiment shown schematically in Figure 2E, optical crosstalk suppression is achieved using spacers 295 constructed from opaque materials. In another further embodiment shown schematically in Figure 2F, optical crosstalk suppression is achieved using spacers 296 coated with an opaque coating 297. The embodiments illustrated in Figures 2E and 2F include stacked apertures 294 similar to the stacked apertures 294 illustrated in Figure 2D. In several embodiments, optical crosstalk suppression is achieved without using stacked apertures. In many embodiments, any of a variety of light blocking materials can be used in the construction or coating of spacers to achieve optical isolation.

Lens Properties

[0076] Figures 3A and 3B are diagrams illustrating changes in the height t of a lens element pursuant to changes in dimensions in an x-y plane. A lens element 320 in Figure 3B is scaled by 1/n compared to a lens element 310 in Figure 3A. Note that during scaling it is important to keep the same F# so image properties don't change. As the diameter L/n of the lens element 320 is smaller than the diameter L by a factor of n, the height t/n of the lens element 320 is also smaller than the height t of the lens element 310 by a factor of n. Hence, by using an array of smaller lens elements, the height of the camera array assembly can be reduced significantly. The reduced height of the camera array assembly may be used to design less aggressive lenses having better optical properties such as improved chief ray angle, reduced distortion, and improved color aberration.

[0077] Figure 3C illustrates improving a chief ray angle (CRA) by reducing the thickness of the camera array assembly. CRA1 is the chief ray angle for a single lens covering an entire camera array. Although the chief ray angle can be reduced by increasing the distance between the camera array and the lens, the thickness constraints imposes constraints on increasing the distance. Hence, the CRA1 for camera array having a single lens element is large, resulting in reduced optical performance. CRA2 is the chief ray angle for an imager in the camera array that is scaled in thickness as well as other dimensions. The CRA2 remains the same as the CRA1 of the conventional camera array and results in no improvement in the chief ray angle. By modifying the distance between the imager and the lens element as illustrated in Figure 3C, however, the chief ray angle CRA3 in the camera array assembly may be reduced compared to CRA1 or CRA2, resulting in better optical performance. As described above, the camera arrays according to the present invention has reduced thickness requirements, and therefore, the distance of the lens element and the camera array may be increased to improve the chief ray angle. This relaxed CRA, in turn, results in a lower F# and improved Modulation Transfer Function (MTF).

[0078] Specifically, one of issues raised in camera design is how to correct for field curvature. An image projected through a lens is not planar, but has an inherently curved surface. One way to correct this field curvature is to position a thick negative lens element 312 close to or directly on the imager surface 314. The negative lens element planarizes the various angled beams of light 316 from the image, thereby addressing the field curvature problem. Such field flattened images provide superior image performance, allow for the

manufacture of array cameras with relaxed TTL requirements, and deliver very homogeneous MTF. However, one problem with this approach is that this field flattening approach intrinsically requires a high CRA. This makes the technique unsuitable for most cameras; however, the camera arrays of the current invention allow for the use of backside imaging (BSI). Positioning the image sensor behind the substrate relaxes the CRA angle requirement, thereby allowing for the use of the negative lens element field flattening approach shown in Figure 3D.

[0079] Another advantage of the array camera relates to chromatic aberrations. Specifically, in a conventional polychromatic lens, the lens has to be corrected for chromatic aberrations, because the focal length through the lens is different for different wavelengths of light. As a result, it is necessary to compromise the performance of the lens for some of the color wavelengths to get acceptable overall color performance. By making each optical channel narrow spectral band, color aberration is reduced and/or prevented, and each lens may be optimized to a specific color wavelength. For example, an imager receiving visible or near-IR spectrum may have a lens element specifically optimized for this spectral band of light. For imagers detecting other light spectrum, the lens element may be constructed with different properties, such as radii of curvature, so that a constant focal length across all wavelengths of light is achieved so that, in turn, the focal plane is the same for different spectral bands of light. The matching of the focal plane across different wavelengths of light increases the sharpness of image captured at the imager and reduces longitudinal chromatic aberration. Because each lens element may be designed to direct a narrow band of light, the concomitant lack of color aberration means that the lens elements can be subject to less rigorous design constraints, yet produce better or equivalent performance compared to conventional lens element covering a wide light spectrum. In particular, there is no need to undertake costly aberration balancing correction. What is more, simple lenses generally have better MTF and lower F# (higher sensitivity). It should be noted that although the lenses used in these array cameras have much smaller color aberrations when compared to conventional polychromatic lenses, each lens is still designed to focus a certain wavelength-bandwidth. Accordingly, in one embodiment each of these "monochromatic" lenses can be optimally color corrected by using combinations of high and low Abbe number materials (different optical dispersions).

[0080] Light of different wavelengths having different focal lengths (longitudinal color aberration) is not the only type of aberration that occurs in polychromatic optical systems. The refractive index of a lens is dependent on the wavelength of light passing through the lens. As a result, a lens will impart different magnification to colors of different wavelengths. For example, the red wavelength band might have a slightly smaller magnification than green, and green may in turn have a slightly smaller magnification than blue. If the images obtained from these different wavelengths of light are then overlaid without correction, the image will lose resolution because the different colors will not overlap correctly. Based on the properties of the material, the differential lateral distortions of the color magnification can be determined and then corrected. Correction can be accomplished by restricting the profiles of the lenses so that each color has the same magnification, but this reduces the possible degrees of freedom available for lens manufacture, and reduces the ability to optimize MTF. Accordingly, in one embodiment of the camera array, lateral distortion is permitted optically, and then corrected after imaging computationally. The electronic correction of the lateral color of the lens can actually provide improvements to system performance above and beyond simply correcting for the original distortion, because such correction directly improves the resolution of the system in terms of polychromatic MTF. In particular, lateral color aberrations in a lens can be seen as a color dependent distortion of the lens. By mapping all differently distorted single color images of an object back to the same rectangle, perfect overlap can be achieved in the full color image resulting in the polychromatic MTF being the same as the monochromatic one (not only due to the individual color channel color-blur correction, but also as a result of the exact superposition of the different colors).

[0081] Yet another advantage to using many lenses, each optimized for use with a narrow band of light, is that the there is no restriction on the type of lens that may be used. In particular, the array camera allows for the use of diffractive, refractive, Fresnel lenses, or combinations of these types of lenses. Diffractive lenses are attractive because they allow for the creation of complex wavefronts with an essentially flat optical element, and they are also relatively simple to manufacture. In conventional cameras it is not possible to use diffractive lenses because having a single imager means that the lens must be able to efficiently transmit a wide spectrum of light, and while diffractive lenses are very efficient at transmitting narrow wavelength bands of light, there is a steep drop-off in performance for wavelengths of light outside of this optimized range. Because each array of the current camera may be focused on

a narrow wavelength of light, the narrow optimized wavelength band of these diffractive lenses is not a limiting factor.

[0082] Other advantages of smaller lens elements include, among others, reduced cost, reduced amount of materials, and the reduction in the manufacturing steps. By providing n^2 lenses that are $1/n$ the size in x and y dimension (and thus 1/n thickness), the wafer size for producing the lens element may also be reduced. This reduces the cost and the amount of materials considerably. Further, the number of lens substrates is reduced, which results in a reduced number of manufacturing steps and reduced attendant yield costs. The placement accuracy required to register the lens array to the imagers is typically no more stringent than in the case of a conventional imager because the pixel size for the camera array according to the present invention may be substantially the same as a conventional image sensor. In addition, monochromatic aberrations scale with lens diameter. Because array cameras are able to use smaller lenses, any aberrations that exist are smaller so it is possible to use lenses with simpler profiles. This results in a system that is simultaneously better and less costly to fabricate. Smaller sized lenses also have a lower volume, which results in lower sag or shrinkage during manufacture. Shrinkage is bad for replication because it deforms the desired lens profile, and results in the need for the fabricator to precompensate for the predicted level of sag so that the final lens shape will be correct. This precompensation is difficult to control. With lower sag/shrinkage it is not necessary to have these tight fabrication controls, again lowering the overall cost of the manufacture of the lenses.

[0083] In one embodiment, the WLO fabrication process includes: (i) incorporating lens element stops by plating the lens element stops onto the substrate before lens molding, and (ii) etching holes in the substrate and performing two-sided molding of lenses through the substrate. The etching of holes in the substrate is advantageous because index mismatch is not caused between plastic and substrate. In this way, light absorbing substrate that forms natural stops for all lens elements (similar to painting lens edges black) may be used.

In one embodiment, filters are part of the imager. In another embodiment, filters are part of a WLO subsystem. In an embodiment including a filter, it is preferred to dispose the filter (whether CFA, IR and/or VIS) into or close to the aperture stop surface and not at the imager sensor surface, because when positioned at a distance from the imager sensor small defects in those filter layers are averaged out over all entrance pupil positions, and are therefore less visible.

Imaging System and Processing Pipeline

[0084] Figure 4 is a functional block diagram illustrating an imaging system 400, according to one embodiment. The imaging system 400 may include, among other components, the camera array 410, an image processing pipeline module 420 and a controller 440. The camera array 410 includes two or more imagers, as described above in detail with reference to Figures 1 and 2. Images 412 are captured by the two or more imagers in the camera array 410.

[0085] The controller 440 is hardware, software, firmware or a combination thereof for controlling various operation parameters of the camera array 410. The controller 440 receives inputs 446 from a user or other external components and sends operation signals 442 to control the camera array 410. The controller 440 may also send information 444 to the image processing pipeline module 420 to assist processing of the images 412.

[0086] The image processing pipeline module 420 is hardware, firmware, software or a combination for processing the images received from the camera array 410. The image processing pipeline module 420 processes multiple images 412, for example, as described below in detail with reference to Figure 5. The processed image 422 is then sent for display, storage, transmittal or further processing.

[0087] Figure 5 is a functional block diagram illustrating the image processing pipeline module 420, according to one embodiment. The image processing pipeline module 420 may include, among other components, an upstream pipeline processing module 510, an image pixel correlation module 514, a parallax confirmation and measurement module 518, a parallax compensation module 522, a super-resolution module 526, an address conversion module 530, an address and phase offset calibration module 554, and a downstream color processing module 564.

[0088] The address and phase offset calibration module 554 is a storage device for storing calibration data produced during camera array characterization in the manufacturing process or a subsequent recalibration process. In several embodiments, the calibration data can indicate mapping between the addresses of physical pixels 572 in the imagers and the logical addresses 546, 548 of an image. In other embodiments, a variety of calibration data appropriate to a specific application can be utilized in the address and phase offset calibration module.

[0089] The address conversion module 530 performs normalization based on the calibration data stored in the address and phase offset calibration module 554. Specifically, the address conversion module 530 converts "physical" addresses of the individual pixels in the image to "logical" addresses 548 of the individual pixels in the imagers or vice versa. In order for super-resolution processing to produce an image of enhanced resolution, the phase difference between corresponding pixels in the individual imagers needs to be resolved. The super-resolution process may assume that for each pixel in the resulting image the set of input pixels from each of the imager is consistently mapped and that the phase offset of the image captured by each imager is already known with respect to the position of the pixel in the resulting image. Alternatively, the pixel offsets can be estimated prior to the superresolution process. The address conversion module 530 resolves such phase differences by converting the physical addresses in the images 412 into logical addresses 548 of the resulting image for subsequent processing.

[0090] The images 412 captured by the imagers 540 are provided to the upstream pipeline processing module 510. The upstream pipe processing module 510 may perform one or more of normalization of the color planes, Black Level calculation and adjustments, fixed noise compensation, optical PSF (point spread function) deconvolution, noise reduction, lateral color correction and crosstalk reduction.

[0091] In one embodiment, the upstream pipeline processing module also performs temperature normalization. Temperature normalization corrects for changes in the refractive index of the optical components through which the imagers receive light that result from changes in the temperature of the camera during use. In several embodiments, the temperature normalization process involves determining the temperature of the camera array by measuring the dark current of one or an average of a number of the camera array's imagers. Using this measurement, a refractive index normalization is performed by picking the correct point spread function from temperature calibration data. Different point spread functions may be obtained during a temperature dependent refractive index characterization of the camera during manufacture, and stored in the imaging system for use in the temperature normalization process.

[0092] After the image is processed by the upstream pipeline processing module 510, an image pixel correlation module 514 performs calculation to account for parallax that becomes more apparent as objects being captured approach the camera array. Specifically, the image

pixel correlation module 514 aligns portions of images captured by different imagers to compensate for the parallax. In one embodiment, the image pixel correlation module 514 compares the difference between the average values of neighboring pixels with a threshold and flags the potential presence of parallax when the difference exceeds the threshold. The threshold may change dynamically as a function of the operating conditions of the camera array. Further, the neighborhood calculations may also be adaptive and reflect the particular operating conditions of the selected imagers.

[0093] The image is then processed by the parallax confirmation and measurement module 518 to detect and meter the parallax. In one embodiment, parallax detection is accomplished by a running pixel correlation monitor. This operation takes place in logical pixel space across the imagers with similar integration time conditions. When the scene is at practical infinity, the data from the imagers is highly correlated and subject only to noise-based variations. When an object is close enough to the camera, however, a parallax effect is introduced that changes the correlation between the imagers. Due to the spatial layout of the imagers, the nature of the parallax-induced change is consistent across all imagers. Within the limits of the measurement accuracy, the correlation difference between any pair of imagers dictates the difference between any other pair of imagers and the differences across the other imagers. This redundancy of information enables highly accurate parallax confirmation and measurement by performing the same or similar calculations on other pairs of imagers. If parallax is present in the other pairs, the parallax should occur at roughly the same physical location of the scene taking into account the positions of the imagers. The measurement of the parallax may be accomplished at the same time by keeping track of the various pair-wise measurements and calculating an "actual" parallax difference as a least squares (or similar statistic) fit to the sample data. Other methods for detecting the parallax may include detecting and tracking vertical and horizontal high-frequency image elements from frame-to-frame.

[0094] The parallax compensation module 522 processes images including objects close enough to the camera array to induce parallax differences larger than the accuracy of the phase offset information required by super resolution process. The parallax compensation module 522 uses the scan-line based parallax information generated in the parallax detection and measurement module 518 to further adjust mapping between physical pixel addresses and logical pixel addresses before the super-resolution process. There are two cases that occur

during this processing. In a more common case, addressing and offsetting adjustment are required when the input pixels have shifted positions relative to the image-wise-corresponding pixels in other imagers. In this case, no further processing with respect to parallax is required before performing super-resolution. In a less common case, a pixel or group of pixels are shifted in such a way that exposes the occlusion set. In this case, the parallax compensation process generates tagged pixel data indicating that the pixels of the occlusion set should not be considered in the super-resolution process.

[0095] After the parallax change has been accurately determined for a particular imager, the parallax information 524 is sent to the address conversion module 530. The address conversion module 530 uses the parallax information 524 along with the calibration data 558 from the address and phase offset calibration module 554 to determine the appropriate X and Y offsets to be applied to logical pixel address calculations. The address conversion module 530 also determines the associated sub-pixel offset for a particular imager pixel with respect to pixels in the resulting image 428 produced by the super-resolution process. The address conversion module 530 takes into account the parallax information 524 and provides logical addresses 546 accounting for the parallax.

[0096] After performing the parallax compensation, the image is processed by the super-resolution module 526 to obtain a high resolution synthesized image 422 from low resolution images, as described below in detail. The synthesized image 422 may then be fed to the downstream color processing module 564 to perform one or more of the following operations: focus recover, white balance, color correction, gamma correction, RGB to YUV correction, edge-aware sharpening, contrast enhancement and compression.

[0097] The image processing pipeline module 420 may include components for additional processing of the image. For example, the image processing pipeline module 420 may include a correction module for correcting abnormalities in images caused by a single pixel defect or a cluster of pixel defects. The correction module may be embodied on the same chip as the camera array, as a component separate from the camera array or as a part of the super-resolution module 526.

Super-Resolution Processing

[0098] In one embodiment, the super-resolution module 526 generates a higher resolution synthesized image by processing low resolution images captured by the imagers 540. The

overall image quality of the synthesized image is higher than images captured from any one of the imagers individually. In other words, the individual imagers operate synergistically, each contributing to higher quality images using their ability to capture a narrow part of the spectrum without sub-sampling. The image formation associated with the super-resolution techniques may be expressed as follows:

$$y_k = W_k \cdot x + n_k, \forall\, k = 1 \ldots p \qquad \ldots\ldots\ldots\ldots\ldots \text{equation} \qquad (2)$$

where W_k represents the contribution of the HR scene (x) (via blurring, motion, and sub-sampling) to each of the LR images (y_k) captured on each of the k imagers and n_k is the noise contribution.

Imager Configurations

[0099] Figures 6A through 6F illustrate various configurations of imagers for obtaining a high resolution image through a super-resolution process, according to embodiments of the present invention. In Figures 6A through 6F, "R" represents an imager having a red filter, "G" represents a imager having a green filter, "B" represents an imager having a blue filter, "P" represents a polychromatic imager having sensitivity across the entire visible spectra and near-IR spectrum, and "I" represents an imager having a near-IR filter. The polychromatic imager may sample image from all parts of the visible spectra and the near-IR region (i.e., from 650nm to 800nm). In the embodiment of Figure 6A, the center columns and rows of the imagers include polychromatic imagers. The remaining areas of the camera array are filled with imagers having green filters, blue filters, and red filters. The embodiment of Figure 6A does not include any imagers for detecting near-IR spectrum alone.

[00100] The embodiment of Figure 6B has a configuration similar to conventional Bayer filter mapping. This embodiment does not include any polychromatic imagers or near-IR imagers. As described above in detail with reference to Figure 1, the embodiment of Figure 6B is different from conventional Bayer filter configuration in that each color filter is mapped to each imager instead of being mapped to an individual pixel.

[00101] Figure 6C illustrates an embodiment where the polychromatic imagers form a symmetric checkerboard pattern. Figure 6D illustrates an embodiment where four near-IR imagers are provided. Figure 6E illustrates an embodiment with irregular mapping of imagers. Figure 6F illustrates an embodiment where a 5 × 5 sensor array is organized into 17 imagers having green filters, four imagers having red filters, and four imagers having blue

filters. The sensors are distributed symmetrically around the central axis of the imaging array. As is discussed further below, distributing the imagers in this way prevents pixels that can be imaged by a sensor from being occluded from sensors capturing other wavelengths of light. The embodiments of Figures 6A through 6F are merely illustrative and various other layouts of imagers can also be used.

[00102] The use of polychromatic imagers and near-IR imagers is advantageous because these sensors may capture high quality images in low lighting conditions. The images captured by the polychromatic imager or the near-IR imager are used to denoise the images obtained from regular color imagers. However, as discussed above, these polychromatic lenses require that an associated color correction technique be used to address color aberrations inherent in a single lens trying to capture all wavelengths of light and deliver it to the same focal plane. Any conventional color correction technique may be utilized with the proposed array cameras.

Imager Layout

[00103] The premise of increasing resolution by aggregating multiple low resolution images relies upon the different low resolution images representing slightly different viewpoints of the same scene. If the LR images are all shifted by integer units of a pixel, then each image contains essentially the same information. Therefore, there is no new information in the LR images that can be used to create a HR image. In camera arrays according to embodiments of the invention, the layout of the imagers in the array may be preset and controlled so that each imager in a row or a column captures an image that is shifted a fixed sub-pixel distance relative to the images captured by its neighboring imagers. Ideally, the images captured by each imager are spatially offset from the other imagers in such a way as to provide uniform sampling of the scene or the light field and the uniformity of sampling is such that the LR images captured by each of the imagers yields non-redundant information about the sampled scene (light field). Such non-redundant information about the scene can be utilized by subsequent signal processing processes to synthesize a single HR image.

[00104] A sub-pixel shift between the images captured by two imagers is not, however, sufficient to ensure uniformity of sampling. The uniformity of sampling or sampling diversity of two imagers is a function of object distance. The sampled space by pixels of a

pair of imagers is illustrated in FIG. 6G. A first set of rays (610) map to pixels of imager A, while a second set of rays (620) map to pixels of imager B. Conceptually, two adjacent rays from a given imager define the part of the object space that is sampled by a specific pixel in that imager. At distance $z1$ from the camera plane, there is sufficient sampling diversity since the rays of the pixels of imager A are partially offset from the rays of the pixels of imager B. As the distance decreases there are specific distances ($z2$, $z3$, $z4$) where there is no sampling diversity between imager A and imager B. The lack of sampling diversity between the two imagers quite simply implies that there is no additional information in the scene captured by imager B as compared to that captured by imager A. As is discussed further below, an increased number of imagers in an array camera can mitigate the impact of object distances at which pair of imagers' sample space fully overlap. When a pair of imagers lack sampling diversity, the other imagers in the array provide the necessary sampling diversity to achieve resolution enhancement. Consequently, the ability of an imager system utilizing a 2x2 array of imagers to achieve superresolution is typically more limited than camera systems in accordance with embodiments of the invention that use a larger camera array.

[00105] Referring back to the camera array structures illustrated in FIGS. 2A – 2D the wafer level optics includes a plurality of lens elements, where each lens element covers one of the sensors in the array. The physical layout of pixels in a single imager of a camera array in accordance with an embodiment of the invention is illustrated in FIG. 6H. The imager is an array of pixels 650 overlaid with color filters 652 and microlenses 654. The microlenses that sit on top of the color filters are used to focus light on the active area of each underlying pixel. The microlenses can be thought of as sampling the continuous light field in object space sampled by the main lens. Whereas the main lens samples the scene radiance light field, the micro-lenses sample the sensor irradiance light field.

[00106] The main lens associated with each imager maps the points in the object space to points in the image space such at that the mapping is bijective (onto-to-one and onto). Each microlens samples a finite extent of the sensor irradiance light field. The sensor irradiance light field is continuous and is the result of a bijective mapping from the object space. Thus, the microlens sampling of a finite extent of the sensor irradiance light field is also a sampling of a corresponding finite extent of the scene radiance light field in object space.

[00107] Moving the microlens by a small amount δ laterally along the plain of the imager pixels changes the sampled object space at a certain distance z_k by a correspondingly

appropriate factor δ. With an $n \times n$ ($n > 2$) array camera, we can choose a baseline microlens shift can be determined by the main lens profile (for example, the chief ray angle) for a baseline imager. For each of the other imagers that sample the same wavelength as the baseline imager, the microlenses of each of the pixels in the imager are shifted by a sub-pixel amount to sample a different part of the scene radiance light field. Thus for a set of imagers arranged in an $n \times n$ grid, the sub-pixel shift for a imager that images the same wavelengths as the baseline imager (1,1) at a grid location (i,j) ($1 \leq i,j \leq n$) is governed by (δ_x, δ_y) where,

$$\frac{(i-1)}{n} \times pixelsize < \delta_x \leq \frac{i}{n} \times pixelsize$$
$$\frac{(j-1)}{n} \times pixelsize < \delta_y \leq \frac{j}{n} \times pixelsize$$

[00108] Many camera arrays in accordance with embodiments of the invention include significantly more Green imagers than Red and Blue imagers. For example, the array camera illustrated in FIG. 6F includes 17 Green imagers, 4 Red imagers, and 4 Blue imagers. For the purpose of calculating the sub-pixel shifts, the Green imagers can be treated as an $n \times n$ grid. Whereas the Red imagers and the Blue imagers can each be treated as a 2×2 grid for the purpose of calculating the sub-pixel shifts.

[00109] The sub-pixel shifts discussed above are determined relative to a baseline imager located at the corner of the grid, many embodiments of the invention utilize radial sub-pixel shifts from a baseline imager located at the center of the sensor array. In several embodiments, the radial sub-pixel shifts are chosen so the sub-pixel shifts are evenly distributed to enable the greatest sampling diversity.

[00110] The constraints on microlens sub-pixel shifts defined above achieve the highest increases in diversity and can enable the greatest increases in resolution through superresolution processing. Sub-pixel shifts that do not satisfy the constraints, but still provide an increase in sampling diversity can also be used to enable some increase in resolution through superresolution processing. Therefore, embodiments of the invention are not limited to microlens shifts that result in the greatest increases in diversity and in many instances utilize a variety of different microlens shift configurations that provide at least some increase in sampling diversity and that are satisfactory for the requirements of a specific application.

Symmetry of Imager Placement in Camera Array

[00111] An issue of separating the spectral sensing elements into different imagers is parallax caused by the physical separation of the imagers. By ensuring that the imagers are symmetrically placed, at least two imagers can capture the pixels around the edge of a foreground object. In this way, the pixels around the edge of a foreground object may be aggregated to increase resolution as well as avoiding any occlusions. In the absence of a symmetrical distribution, a pixel around the edge of a foreground object that is visible to a first imager, for example a Red camera, may be occluded to a second imager that captures different wavelengths, for example a blue imager. Accordingly, color information for the pixel cannot be accurately reconstructed. By symmetrically distributing the sensors, the likelihood that a foreground object will occlude pixels is significantly reduced.

[00112] Pixel occlusion caused by an asymmetric distribution of Red and Blue imagers in a simple array is illustrated in FIG. 6I. A pair of Red imagers 672 is located on the left hand side of the camera array 670 and a pair of Blue imagers 674 is located on the right hand side of the camera array. A foreground object 676 is present and the Red imagers 672 are capable of imaging regions beyond the foreground object on the left hand side of the foreground object. However, the foreground object occludes the Red imagers from imaging these regions. Therefore, the array camera is incapable of reconstructing color information for these regions.

[00113] An array that includes a symmetric distribution of Red and Blue imagers in accordance with an embodiment of the invention is illustrated in FIG. 6J. The camera array 780 includes a pair of Red imagers 782 symmetrically distributed around the central axis of the camera array and a pair of Blue imagers 784 symmetrically distributed around the central axis of the camera array. Due to the even distribution, a Red imager and a Blue imager are both able to image beyond the foreground object 786 on the left hand side of the foreground object and a Red imager and a Blue imager are both able to image beyond the foreground object on the right hand side of the foreground object.

[00114] The symmetrical arrangement of the simple embodiment illustrated in FIG. 6J can be generalized to array cameras including Red, Green, Blue cameras and/or additional polychromatic or near-IR cameras. By distributing each of the different types of imagers symmetrically around the central axis of the camera array, the effects of parallax introduced

by foreground objects can be significantly reduced and color artifacts that would otherwise be introduced, avoided.

[00115] The effects of parallax on the sampling of color can also be reduced by using parallax information in polychromatic imagers to improve the accuracy of the sampling of color from the color filtered imagers.

Use of Near-IR Imagers to Obtain Improved High Resolution Images

[00116] In one embodiment, near-IR imagers are used to determine relative luminance differences compared to a visible spectra imager. Objects have differing material reflectivity results in differences in the images captured by the visible spectra and the near-IR spectra. At low lighting conditions, the near-IR imager exhibits a higher signal to noise ratios. Therefore, the signals from the near-IR sensor may be used to enhance the luminance image. The transferring of details from the near-IR image to the luminance image may be performed before aggregating spectral images from different imagers through the super-resolution process. In this way, edge information about the scene may be improved to construct edge-preserving images that can be used effectively in the super-resolution process. The advantage of using near-IR imagers is apparent from equation (2) where any improvement in the estimate for the noise (i.e., n) leads to a better estimate of the original HR scene (x).

Generation of High Resolution Images

[00117] Figure 7 is a flowchart illustrating a process of generating an HR image from LR images captured by a plurality of imagers, according to one embodiment. First, luma images, near-IR images and chroma images are captured 710 by imagers in the camera array. Then normalization is performed 714 on the captured images. The images can be normalized in a variety of ways including but not limited to normalizing the color planes of the images, performing temperature compensation, and mapping physical addresses of the imagers to logical addresses in the enhanced image. In other embodiments, a variety of normalization process appropriate to the specific imagers and imaging applications. Parallax compensation is then performed 720 to resolve any differences in the field-of-views of the imagers due to spatial separations between the imagers. Super-resolution processing is then performed 724 to obtain super-resolved luma images, super-resolved near-IR images, and super-resolved chroma images.

[00118] Then it is determined 728 if the lighting condition is better than a preset parameter. If the lighting condition is better than the parameter, the process proceeds to normalize 730 a super-resolved near-IR image with respect to a super-resolved luma image. A focus recovery is then performed 742. In one embodiment, the focus recovery is performed 742 using PSF (point spread function) deblurring per each color channel. Then the super-resolution is processed 746 based on near-IR images and the luma images. A synthesized image is then constructed 750.

[00119] If it is determined 728 that the lighting condition is not better than the preset parameter, the super-resolved near-IR images and luma images are aligned 734. Then the super-resolved luma images are denoised 738 using the near-IR super-resolved images. Then the process proceeds to performing focus recovery 742 and repeats the same process as when the lighting condition is better than the preset parameter. Then the process terminates.

Normalization of Color Planes

[00120] The relative response of each of the Red, Green, Blue imagers across the imaging planes varies. The variance can be the result of many factors including the optical alignment of the lens and asymmetrical sensor light path geometry. For a given lens and imager, the variance can be compensated for by calibration and normalization. Without compensation, the variance can give rise to artifacts such as color shading.

[00121] A process for normalizing a imager with respect to a baseline imager, which is typically a Green imager located in the center of the camera array, in accordance with an embodiment of the invention is discussed below with reference to the normalization of a Red imager with respect to a baseline Green imager. A similar process can be used to normalize Blue imagers with respect to a baseline Green imager. In many embodiments, the process is applied to normalize each Red and Blue imager in a camera array.

[00122] A normalization surface can be calibrated by first capturing a scene with flat reflectance, and calculating a color ratio surface to serve as the basis for normalization. An ideal normalization surface is uniform and can be described as:

$$\text{Color Ratio } G/R = G(i,j) / R(i,j) = K = G_{center} / R_{center}$$

where (i,j) describe the pixel position, K is a constant, and G_{center}, and R_{center}, describe the pixel value at the center position.

[00123] The output pixel values of the calibration scene contain the ideal pixel values plus noise plus black level offset, and can be described as follows:

$$SR(i,j) = R(i,j) + \text{Noise R } (i,j) + \text{black offset}$$

$$SG(i,j) = G(i,j) + \text{Noise G } (i,j) + \text{black offset}$$

where SR, and SG are the output pixel values from each imager.

[00124] A process for calibrating the sensor in accordance with an embodiment of the invention is illustrated in FIG. 7A. The process 760 includes removing (762) the black level offset from the sensor pixel values, and low pass filtering (764) the image planes to reduce noise. The normalization plane is calculated (766) and several embodiments are calculated as follows:

$$\text{Norm R} = G(i,j) / (R(i,j) \times (G_{center} / R_{center}))$$

where G_{center}, and R_{center}, are the pixel values at the center position.

[00125] Following the calculation of the normalization plane, an averaging filter can be applied (768) and the values of the Norm R plane are stored (770).

[00126] The cost of carrying all of the normalization data for each of the sensors in a sensor array can be quite high. Therefore, many embodiments scan the Norm R plane using a space filling curve to form a one dimensional array. The resultant one dimensional array can be modeled in a variety of different ways including being modeled as a polynomial with suitable order. In several embodiments, the polynomials of the fitted polynomial are stored (810) as parameters that are used during calibration to reconstruct the two dimensional normalization plane. The construction of a space filling curve in accordance with several embodiments of the invention is discussed further below.

[00127] In several embodiments, a space filling curve is used to form a one dimensional array describing a normalization plane. A space filling curve, which is constructed using a spiral scan, is illustrated in FIG. 7B. A space filling curve 780 can be constructed by starting at the center of the normalization plane 781 and traversing a four sided square outwards. Each side of the square expands by two pixels compared to the previous square such that every pixel will be traversed exactly once. In the illustrated embodiment, each position 782 which is marked with an 'X' corresponds to a valid pixel position. The imager may not have a square geometry, so the scan path may traverse empty space (indicated as dashed lines). For each position traversed, if it is a valid pixel position, a new data entry is added to the one dimensional data array. Otherwise, the traversing continues without adding a new value to

the data array. In many embodiments, the one dimensional data array can be efficiently approximated using a 6^{th} order polynomial that can be represented using the seven coefficients of the polynomial. Given that calibration data is typically required for each Red and Blue imager, expressing the normalization planes as coefficients of a polynomial represents a significant reduction in storage requirements. In many embodiments, higher or lower order polynomials, other functions, and/or other compressed representations are utilized to represent the normalization plane in accordance with the requirements of a specific application.

[00128] The data value along each side exhibits a fixed geometric relationship. The optical path to the focal point of the lens is shorter for the cells near the center line. The base sensitivity can be thought of as a one dimensional center cut of the calibration surface and approximated by a low order polynomial. The sensitivity polynomial can be either stored as a machine constant (i.e., common to all devices with the same design), or stored along with the scan polynomial to provide additional flexibility. Accordingly, many embodiments of the invention adjust the pixel value based upon the distance factor as follows. For each side scan, one of the coordinates will be a constant, i.e., constant 'y' for horizontal scan and constant 'x' for vertical scan. For each pixel in the side scan, the sensitivity factor is adjusted towards the constant 'x' or 'y' distance.

[00129] By way of example, for a horizontal scan the base value can be found by evaluating the sensitivity polynomial based on the distance 'y' from the center. In many embodiments, a suitable polynomial is a fourth order polynomial. Although other polynomials and/or other functions can be utilized in accordance with the requirements of a specific application. For each pixel in the scan path, the distance from the surface origin is used to find the corresponding sensitivity from the polynomial in the same manner. The pixel value is multiplied by an adjustment factor and then stored in the scanned data array. This adjustment factor is calculated by dividing the base value with the current sensitivity value. For the vertical scan a similar method can be applied. Although the example uses a polynomial based sensitivity adjustment, other sensitivity functions and/or adjustments can be utilized depending upon the requirements of a specific application in accordance with various embodiments of the invention.

[00130] Once calibration data has been obtained for an imager, the calibration data can be used in the normalization of pixel information captured by the imager. The process typically

involves retrieving the stored calibration data, removing the black offset from the captured image and multiplying the resultant values with the normalization plane. When the normalization plane is expressed as a polynomial in the manner outlined above, the polynomial is used to generate a one-dimensional array and an inverse scan of the one-dimensional array is used to form the two dimensional normalization plane. Where a sensitivity adjustment was applied during calibration, an adjustment factor is calculated that is the reciprocal of the adjustment factor applied during the calibration scan and the adjustment factor is applied to the values in the one dimensional array during the inverse scan. When other space filling curves, representations of the resulting one dimensional data array, and/or sensitivity adjustments are performed during the calibration process, the normalization process is adjusted accordingly.

[00131] As can be readily appreciated, calibration and normalization processes in accordance with embodiments of the invention can be applied to each of the Red and Blue imagers in the camera array. In many embodiments, a Green imager located in the center of the camera array is used when performing the calibration. In other embodiments, a different Green imager and/or multiple Green imagers can be utilized in the calibration of the Red and Blue imagers in the camera array.

Image Fusion of Color Images with Near-IR Images

[00132] The spectral response of CMOS imagers is typically very good in the near-IR regions covering 650nm to 800nm and reasonably good between 800nm and 1000nm. Although near-IR images having no chroma information, information in this spectral region is useful in low lighting conditions because the near-IR images are relatively free of noise. Hence, the near-IR images may be used to denoise color images under the low lighting conditions.

[00133] In one embodiment, an image from a near-IR imager is fused with another image from a visible light imager. Before proceeding with the fusion, a registration is performed between the near-IR image and the visible light image to resolve differences in viewpoints. The registration process may be performed in an offline, one-time, processing step. After the registration is performed, the luminance information on the near-IR image is interpolated to grid points that correspond to each grid point on the visible light image.

[00134] After the pixel correspondence between the near-IR image and the visible light image is established, a denoising and detail transfer process may be performed. The denoising process allows transfer of signal information from the near-IR image to the visible light image to improve the overall SNR of the fusion image. The detail transfer ensures that edges in the near-IR image and the visible light image are preserved and accentuated to improve the overall visibility of objects in the fused image.

[00135] In one embodiment, a near-IR flash may serve as a near-IR light source during capturing of an image by the near-IR imagers. Using the near-IR flash is advantageous, among other reasons, because (i) the harsh lighting on objects of interest may be prevented, (ii) ambient color of the object may be preserved, and (iii) red-eye effect may be prevented.

[00136] In one embodiment, a visible light filter that allows only near-IR rays to pass through is used to further optimize the optics for near-IR imaging. The visible light filter improves the near-IR optics transfer function because the light filter results in sharper details in the near-IR image. The details may then be transferred to the visible light images using a dual bilateral filter as described, for example, in Eric P. Bennett et al., "Multispectral Video Fusion," Computer Graphics (ACM SIGGRAPH Proceedings) (July 25, 2006), which is incorporated by reference herein in its entirety.

Dynamic Range Determination by Differing Exposures at Imagers

[00137] An auto-exposure (AE) algorithm is important to obtaining an appropriate exposure for the scene to be captured. The design of the AE algorithm affects the dynamic range of captured images. The AE algorithm determines an exposure value that allows the acquired image to fall in the linear region of the camera array's sensitivity range. The linear region is preferred because a good signal-to-noise ratio is obtained in this region. If the exposure is too low, the picture becomes under-saturated while if the exposure is too high the picture becomes over-saturated. In conventional cameras, an iterative process is taken to reduce the difference between measured picture brightness and previously defined brightness below a threshold. This iterative process requires a large amount of time for convergence, and sometimes results in an unacceptable shutter delay.

[00138] In one embodiment, the picture brightness of images captured by a plurality of imagers is independently measured. Specifically, a plurality of imagers are set to capturing images with different exposures to reduce the time for computing the adequate exposure. For

example, in a camera array with 5 x 5 imagers where 8 luma imagers and 9 near-IR imagers are provided, each of the imagers may be set with different exposures. The near-IR imagers are used to capture low-light aspects of the scene and the luma imagers are used to capture the high illumination aspects of the scene. This results in a total of 17 possible exposures. If exposure for each imager is offset from an adjacent imager by a factor of 2, for example, a maximum dynamic range of 2^{17} or 102dB can be captured. This maximum dynamic range is considerably higher than the typical 48dB attainable in a conventional camera with 8bit image outputs.

[00139] At each time instant, the responses (under-exposed, over-exposed or optimal) from each of the multiple imagers are analyzed based on how many exposures are needed at the subsequent time instant. The ability to query multiple exposures simultaneously in the range of possible exposures accelerates the search compared to the case where only one exposure is tested at once. By reducing the processing time for determining the adequate exposure, shutter delays and shot-to-shot lags may be reduced.

[00140] In one embodiment, the HDR image is synthesized from multiple exposures by combining the images after linearizing the imager response for each exposure. The images from the imagers may be registered before combining to account for the difference in the viewpoints of the imagers.

[00141] In one embodiment, at least one imager includes HDR pixels to generate HDR images. HDR pixels are specialized pixels that capture high dynamic range scenes. Although HDR pixels show superior performances compared to other pixels, HDR pixels show poor performance at low lighting conditions in comparison with near-IR imagers. To improve performance at low lighting conditions, signals from the near-IR imagers may be used in conjunction with the signal from the HDR imager to attain better quality images across different lighting conditions.

[00142] In one embodiment, an HDR image is obtained by processing images captured by multiple imagers by processing, as disclosed, for example, in Paul Debevec et al., "Recovering High Dynamic Range Radiance Maps from Photographs," Computer Graphics (ACM SIGGRAPH Proceedings), (August 16, 1997), which is incorporated by reference herein in its entirety. The ability to capture multiple exposures simultaneously using the imager is advantageous because artifacts caused by motion of objects in the scene can be mitigated or eliminated.

Hyperspectral Imaging by Multiple Imagers

[00143] In one embodiment, a multi-spectral image is rendered by multiple imagers to facilitate the segmentation or recognition of objects in a scene. Because the spectral reflectance coefficients vary smoothly in most real world objects, the spectral reflectance coefficients may be estimated by capturing the scene in multiple spectral dimensions using imagers with different color filters and analyzing the captured images using Principal Components Analysis (PCA).

[00144] In one embodiment, half of the imagers in the camera array are devoted to sampling in the basic spectral dimensions (R, G, and B) and the other half of the imagers are devoted to sampling in a shifted basic spectral dimensions (R', G', and B'). The shifted basic spectral dimensions are shifted from the basic spectral dimensions by a certain wavelength (e.g., 10nm).

[00145] In one embodiment, pixel correspondence and non-linear interpolation is performed to account for the sub-pixel shifted views of the scene. Then the spectral reflectance coefficients of the scene are synthesized using a set of orthogonal spectral basis functions as disclosed, for example, in J.P.S. Parkkinen, J. Hallikainen and T. Jaaskelainen, "Characteristic Spectra of Munsell Colors," J. Opt. Soc. Am., A 6:318 (August 1989), which is incorporated by reference herein in its entirety. The basis functions are eigenvectors derived by PCA of a correlation matrix and the correlation matrix is derived from a database storing spectral reflectance coefficients measured by, for example, Munsell color chips (a total of 1257) representing the spectral distribution of a wide range of real world materials to reconstruct the spectrum at each point in the scene.

[00146] At first glance, capturing different spectral images of the scene through different imagers in the camera array appears to trade resolution for higher dimensional spectral sampling. However, some of the lost resolution may be recovered. The multiple imagers sample the scene over different spectral dimensions where each sampling grid of each imager is offset by a sub-pixel shift from the others. In one embodiment, no two sampling grid of the imager overlap. That is, the superposition of all the sampling grids from all the imagers forms a dense, possibly non-uniform, montage of points. Scattered data interpolation methods may be used to determine the spectral density at each sample point in this non-uniform montage for each spectral image, as described, for example, in Shiaofen Fang et al., "Volume Morphing Methods for Landmark Based 3D Image Deformation" by SPIE vol.

2710, proc. 1996 SPIE Intl Symposium on Medical Imaging, page 404-415, Newport Beach, CA (February 1996), which is incorporated by reference herein in its entirety. In this way, a certain amount of resolution lost in the process of sampling the scene using different spectral filters may be recovered.

[00147] As described above, image segmentation and object recognition are facilitated by determining the spectral reflectance coefficients of the object. The situation often arises in security applications wherein a network of cameras is used to track an object as it moves from the operational zone of one camera to another. Each zone may have its own unique lighting conditions (fluorescent, incandescent, D65, etc.) that may cause the object to have a different appearance in each image captured by different cameras. If these cameras capture the images in a hyper-spectral mode, all images may be converted to the same illuminant to enhance object recognition performance.

[00148] In one embodiment, camera arrays with multiple imagers are used for providing medical diagnostic images. Full spectral digitized images of diagnostic samples contribute to accurate diagnosis because doctors and medical personnel can place higher confidence in the resulting diagnosis. The imagers in the camera arrays may be provided with color filters to provide full spectral data. Such camera array may be installed on cell phones to capture and transmit diagnostic information to remote locations as described, for example, in Andres W. Martinez et al., "Simple Telemedicine for Developing Regions: Camera Phones and Paper-Based Microfluidic Devices for Real-Time, Off-Site Diagnosis," Analytical Chemistry (American Chemical Society) (April 11, 2008), which is incorporated by reference herein in its entirety. Further, the camera arrays including multiple imagers may provide images with a large depth of field to enhance the reliability of image capture of wounds, rashes, and other symptoms.

[00149] In one embodiment, a small imager (including, for example, 20-500 pixels) with a narrow spectral bandpass filters is used to produce a signature of the ambient and local light sources in a scene. By using the small imager, the exposure and white balance characteristics may be determined more accurately at a faster speed. The spectral bandpass filters may be ordinary color filters or diffractive elements of a bandpass width adequate to allow the number of camera arrays to cover the visible spectrum of about 400nm. These imagers may run at a much higher frame rate and obtain data (which may or may not be used for its pictorial content) for processing into information to control the exposure and white balance of

other larger imagers in the same camera array. The small imagers may also be interspersed within the camera array.

Optical Zoom Implemented Using Multiple Imagers

[00150] In one embodiment, a subset of imagers in the camera array includes telephoto lenses. The subset of imagers may have other imaging characteristics that are the same as imagers with non-telephoto lenses. Images from this subset of imagers are combined and super-resolution processed to form a super-resolution telephoto image. In another embodiment, the camera array includes two or more subsets of imagers equipped with lenses of more than two magnifications to provide differing zoom magnifications.

[00151] Embodiments of the camera arrays may achieve its final resolution by aggregating images through super-resolution. Taking an example of providing 5 x 5 imagers with a 3X optical zoom feature, if 17 imagers are used to sample the luma (G) and 8 imagers are used to sample the chroma (R and B), 17 luma imagers allow a resolution that is four times higher than what is achieved by any single imager in the set of 17 imagers. If the number of the imagers is increased from 5 x 5 to 6 x 6, an addition of 11 extra imagers becomes available. In comparison with the 8 Megapixel conventional image sensor fitted with a 3X zoom lens, a resolution that is 60% of the conventional image sensor is achieved when 8 of the additional 11 imagers are dedicated to sampling luma (G) and the remaining 3 imagers are dedicated to chroma (R and B) and near-IR sampling at 3X zoom. This considerably reduces the chroma sampling (or near-IR sampling) to luma sampling ratio. The reduced chroma to luma sampling ratio is somewhat offset by using the super-resolved luma image at 3X zoom as a recognition prior on the chroma (and near-IR) image to resample the chroma image at a higher resolution.

[00152] With 6 x 6 imagers, a resolution equivalent to the resolution of conventional image sensor is achieved at 1X zoom. At 3X zoom, a resolution equivalent to about 60% of conventional image sensor outfitted with a 3X zoom lens is obtained by the same imagers. Also, there is a decrease in luma resolution at 3X zoom compared with conventional image sensors with resolution at 3X zoom. The decreased luma resolution, however, is offset by the fact that the optics of conventional image sensor has reduced efficiency at 3X zoom due to crosstalk and optical aberrations.

[00153] The zoom operation achieved by multiple imagers has the following advantages. First, the quality of the achieved zoom is considerably higher than what is achieved in the conventional image sensor due to the fact that the lens elements may be tailored for each change in focal length. In conventional image sensors, optical aberrations and field curvature must be corrected across the whole operating range of the lens, which is considerably harder in a zoom lens with moving elements than in a fixed lens element where only aberrations for a fixed focal length need to be corrected. Additionally, the fixed lens in the imagers has a fixed chief ray angle for a given height, which is not the case with conventional image sensor with a moving zoom lens. Second, the imagers allow simulation of zoom lenses without significantly increasing the optical track height. The reduced height allows implementation of thin modules even for camera arrays with zooming capability.

[00154] The overhead required to support a certain level of optical zoom in camera arrays according to some embodiments is tabulated in Table 2.

Table 2

No. of Imagers in Camera array	No. of Luma Imagers at different Zoom levels			No. of Chroma Imagers at different Zoom Levels		
	1X	2X	3X	1X	2X	3X
25	17	0	0	8	0	0
a. 36 b.	16	0	8	8	0	4

[00155] In one embodiment, the pixels in the images are mapped onto an output image with a size and resolution corresponding to the amount of zoom desired in order to provide a smooth zoom capability from the widest-angle view to the greatest-magnification view. Assuming that the higher magnification lenses have the same center of view as the lower magnification lenses, the image information available is such that a center area of the image has a higher resolution available than the outer area. In the case of three or more distinct magnifications, nested regions of different resolution may be provided with resolution increasing toward the center.

[00156] An image with the most telephoto effect has a resolution determined by the super-resolution ability of the imagers equipped with the telephoto lenses. An image with the widest field of view can be formatted in at least one of two following ways. First, the wide field image may be formatted as an image with a uniform resolution where the resolution is

determined by the super-resolution capability of the set of imagers having the wider-angle lenses. Second, the wide field image is formatted as a higher resolution image where the resolution of the central part of the image is determined by the super-resolution capability of the set of imagers equipped with telephoto lenses. In the lower resolution regions, information from the reduced number of pixels per image area is interpolated smoothly across the larger number of "digital" pixels. In such an image, the pixel information may be processed and interpolated so that the transition from higher to lower resolution regions occurs smoothly.

[00157] In one embodiment, zooming is achieved by inducing a barrel-like distortion into some, or all, of the array lens so that a disproportionate number of the pixels are dedicated to the central part of each image. In this embodiment, every image has to be processed to remove the barrel distortion. To generate a wide-angle image, pixels closer to the center are sub-sampled relative to outer pixels are super-sampled. As zooming is performed, the pixels at the periphery of the imagers are progressively discarded and the sampling of the pixels nearer the center of the imager is increased.

[00158] In one embodiment, mipmap filters are built to allow images to be rendered at a zoom scale that is between the specific zoom range of the optical elements (e.g., 1X and 3X zoom scales of the camera array). Mipmaps are a precalculated optimized set of images that accompany a baseline image. A set of images associated with the 3X zoom luma image can be created from a baseline scale at 3X down to 1X. Each image in this set is a version of the baseline 3X zoom image but at a reduced level of detail. Rendering an image at a desired zoom level is achieved using the mipmap by (i) taking the image at 1X zoom, and computing the coverage of the scene for the desired zoom level (i.e., what pixels in the baseline image needs to be rendered at the requested scale to produce the output image), (ii) for each pixel in the coverage set, determine if the pixel is in the image covered by the 3X zoom luma image, (iii) if the pixel is available in the 3X zoom luma image, then choose the two closest mipmap images and interpolate (using smoothing filter) the corresponding pixels from the two mipmap images to produce the output image, and (iv) if the pixel is unavailable in the 3X zoom luma image, then choose the pixel from the baseline 1X luma image and scale up to the desired scale to produce the output pixel. By using mipmaps, smooth optical zoom may be simulated at any point between two given discrete levels (i.e., 1X zoom and 3X zoom).

[00159] In one embodiment, zooming is achieved by realizing different Fields Of View (FOV)s by electronically switching between different optical channels having different sensor sizes, but fixed Effective Focal Lengths (EFL)s. In one such embodiment, shown schematically in Figure 8A, variable FOVs are achieved by creating optical channels on the same substrate that have different imager sizes 800 and 802 at the same fixed EFL 804. Using this structure, it would be possible to create an arbitrary number of zoom magnifications by including image sensors with larger or smaller numbers of pixels. This technique is particularly simple to incorporate into WLO array cameras as these variable zoom sensor arrays 800 and 802 can be fabricated directly onto the base camera array substrate without any further modification to the design of the array camera assembly itself.

[00160] In another embodiment, as shown in Figure 8B, different FOVs are achieved by engineering different EFLs 805 into specific optical channels of the camera array 806 while maintaining a fixed imager size 808. Implementing different EFLs on the same substrate stacks, i.e., substrate stacks with constant thicknesses and spacings, is more complicated, because the distance of the principal plane and with it the entrance pupil and consequently the aperture stop 810 with respect to the image sensor 814 needs to be changed in order to change the focal length of the optical channel. In the current embodiment, this is accomplished by the introduction of "dummy substrates" 816, 818 and 820 into the stack 806, such that each zoom channel 822, 824 and 826 has an associated aperture stop 828, 830 and 832 disposed on a different substrate or a different face of a substrate, such that different EFLs can be achieved. As shown, while the distribution and positioning of the lenses (834, 836 and 838) and the aperture stops (828, 830 and 832) on the particular substrate or substrate face is entirely dependent on the desired EFL, in all cases the substrate thicknesses and distances remain fixed. Alternatively, in such an embodiment, each of the substrates could be provided with lenses, but in different distributions in order to allow for different EFLs. Such a structure would allow for higher image quality, but at higher cost.

[00161] In another further embodiment, as shown in Figure 8C, different FOVs can also be achieved by engineering different EFLs 805 using "dummy" substrates in a manner similar to that illustrated in Figure 8B, with the exception that all of the substrates have lenses elements on them in each optical channel. The lens elements, however, have different prescriptions in order to allow different EFLs. Accordingly, any of a variety of configurations of optics and

sensor size, and/or light sensing element size can be utilized with an array camera in accordance with embodiments of the invention to achieve different FOVs.

Capturing Video Images

[00162] In one embodiment, the camera array generates high frame image sequences. The imagers in the camera array can operate independently to capture images. Compared to conventional image sensors, the camera array may capture images at the frame rate up to N time (where N is the number of imagers). Further, the frame period for each imager may overlap to improve operations under low-light conditions. To increase the resolution, a subset of imagers may operate in a synchronized manner to produce images of higher resolution. In this case, the maximum frame rate is reduced by the number of imagers operating in a synchronized manner. The high-speed video frame rates can enables slow-motion video playback at a normal video rate.

[00163] In one example, two luma imagers (green imagers or near-IR imagers), two blue imagers and two green imagers are used to obtain high-definition 1080p images. Using permutations of four luma imagers (two green imagers and two near-IR imagers or three green imagers and one near-IR imager) together with one blue imager and one red imager, the chroma imagers can be upsampled to achieve 120 frames/sec for 1080p video. For higher frame rate imaging devices, the number of frame rates can be scaled up linearly. For Standard-Definition (480p) operation, a frame rate of 240 frames/sec may be achieved using the same camera array.

[00164] Conventional imaging devices with a high-resolution image sensor (e.g., 8 Megapixels) use binning or skipping to capture lower resolution images (e.g., 1080p30, 720p30 and 480p30). In binning, rows and columns in the captured images are interpolated in the charge, voltage or pixel domains in order to achieve the target video resolutions while reducing the noise. In skipping, rows and columns are skipped in order to reduce the power consumption of the sensor. Both of these techniques result in reduced image quality.

[00165] In one embodiment, the imagers in the camera arrays are selectively activated to capture a video image. For example, 9 imagers (including one near-IR imager) may be used to obtain 1080p (1920 x 1080 pixels) images while 6 imagers (including one near-IR imager) may be used to obtain 720p (1280 x 720 pixels) images or 4 imagers (including one near-IR imager) may be used to obtain 480p (720 x 480 pixels) images. Because there is an accurate

one-to-one pixel correspondence between the imager and the target video images, the resolution achieved is higher than traditional approaches. Further, since only a subset of the imagers is activated to capture the images, significant power savings can also be achieved. For example, 60% reduction in power consumption is achieved in 1080p and 80% of power consumption is achieved in 480p.

[00166] Using the near-IR imager to capture video images is advantageous because the information from the near-IR imager may be used to denoise each video image. In this way, the camera arrays of embodiments exhibit excellent low-light sensitivity and can operate in extremely low-light conditions. In one embodiment, super-resolution processing is performed on images from multiple imagers to obtain higher resolution video imagers. The noise-reduction characteristics of the super-resolution process along with fusion of images from the near-IR imager results in a very low-noise images.

[00167] In one embodiment, high-dynamic-range (HDR) video capture is enabled by activating more imagers. For example, in a 5 x 5 camera array operating in 1080p video capture mode, there are only 9 cameras active. A subset of the 16 cameras may be overexposed and underexposed by a stop in sets of two or four to achieve a video output with a very high dynamic range.

Other Applications for Multiple Imagers

[00168] In one embodiment, the multiple imagers are used for estimating distance to an object in a scene. Since information regarding the distance to each point in an image is available in the camera array along with the extent in x and y coordinates of an image element, the size of an image element may be determined. Further, the absolute size and shape of physical items may be measured without other reference information. For example, a picture of a foot can be taken and the resulting information may be used to accurately estimate the size of an appropriate shoe.

[00169] In one embodiment, reduction in depth of field is simulated in images captured by the camera array using distance information. The camera arrays according to the present invention produce images with greatly increased depth of field. The long depth of field, however, may not be desirable in some applications. In such case, a particular distance or several distances may be selected as the "in best focus" distance(s) for the image and based on the distance (z) information from parallax information, the image can be blurred pixel-by-

pixel using, for example, a simple Gaussian blur. In one embodiment, the depth map obtained from the camera array is utilized to enable a tone mapping algorithm to perform the mapping using the depth information to guide the level, thereby emphasizing or exaggerating the 3D effect.

[00170] In one embodiment, apertures of different sizes are provided to obtain aperture diversity. The aperture size has a direct relationship with the depth of field. In miniature cameras, however, the aperture is generally made as large as possible to allow as much light to reach the camera array. Different imagers may receive light through apertures of different sizes. For imagers to produce a large depth of field, the aperture may be reduced whereas other imagers may have large apertures to maximize the light received. By fusing the images from sensor images of different aperture sizes, images with large depth of field may be obtained without sacrificing the quality of the image.

[00171] In one embodiment, the camera array according to the present invention refocuses based on images captured from offsets in viewpoints. Unlike a conventional plenoptic camera, the images obtained from the camera array of the present invention do not suffer from the extreme loss of resolution. The camera array according to the present invention, however, produces sparse data points for refocusing compared to the plenoptic camera. In order to overcome the sparse data points, interpolation may be performed to refocus data from the spare data points.

[00172] In one embodiment, each imager in the camera array has a different centroid. That is, the optics of each imager are designed and arranged so that the fields of view for each imager slightly overlap but for the most part constitute distinct tiles of a larger field of view. The images from each of the tiles are panoramically stitched together to render a single high-resolution image.

[00173] In one embodiment, camera arrays may be formed on separate substrates and mounted on the same motherboard with spatial separation. The lens elements on each imager may be arranged so that the corner of the field of view slightly encompasses a line perpendicular to the substrate. Thus, if four imagers are mounted on the motherboard with each imager rotated 90 degrees with respect to another imager, the fields of view will be four slightly overlapping tiles. This allows a single design of WLO lens array and imager chip to be used to capture different tiles of a panoramic image.

[00174] In one embodiment, one or more sets of imagers are arranged to capture images that are stitched to produce panoramic images with overlapping fields of view while another imager or sets of imagers have a field of view that encompasses the tiled image generated. This embodiment provides different effective resolution for imagers with different characteristics. For example, it may be desirable to have more luminance resolution than chrominance resolution. Hence, several sets of imagers may detect luminance with their fields of view panoramically stitched. Fewer imagers may be used to detect chrominance with the field of view encompassing the stitched field of view of the luminance imagers.

[00175] In one embodiment, the camera array with multiple imagers is mounted on a flexible motherboard such that the motherboard can be manually bent to change the aspect ratio of the image. For example, a set of imagers can be mounted in a horizontal line on a flexible motherboard so that in the quiescent state of the motherboard, the fields of view of all of the imagers are approximately the same. If there are four imagers, an image with double the resolution of each individual imager is obtained so that details in the subject image that are half the dimension of details that can be resolved by an individual imager. If the motherboard is bent so that it forms part of a vertical cylinder, the imagers point outward. With a partial bend, the width of the subject image is doubled while the detail that can be resolved is reduced because each point in the subject image is in the field of view of two rather than four imagers. At the maximum bend, the subject image is four times wider while the detail that can be resolved in the subject is further reduced.

Offline Reconstruction and Processing

[00176] The images processed by the imaging system 400 may be previewed before or concurrently with saving of the image data on a storage medium such as a flash device or a hard disk. In one embodiment, the images or video data includes rich light field data sets and other useful image information that were originally captured by the camera array. Other traditional file formats could also be used. The stored images or video may be played back or transmitted to other devices over various wired or wireless communication methods.

[00177] In one embodiment, tools are provided for users by a remote server. The remote server may function both as a repository and an offline processing engine for the images or video. Additionally, applets mashed as part of popular photo-sharing communities such as Flikr, Picasaweb, Facebook etc. may allow images to be manipulated interactively, either

individually or collaboratively. Further, software plug-ins into image editing programs may be provided to process images generated by the imaging device 400 on computing devices such as desktops and laptops.

[00178] Various modules described herein may comprise a general-purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, application specific integrated circuits (ASICs), or any type of media suitable for storing electronic instructions, and each coupled to a computer system bus. Furthermore, the computers referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

[00179] While particular embodiments and applications of the present invention have been illustrated and described herein, it is to be understood that the invention is not limited to the precise construction and components disclosed herein and that various modifications, changes, and variations may be made in the arrangement, operation, and details of the methods and apparatuses of the present invention without departing from the spirit and scope of the invention as it is defined in the appended claims.

What is claimed:

1. 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;

control circuitry configured to capture images formed on the light sensing elements of each of the imagers; and

a super-resolution processing module configured to generate at least one higher resolution super-resolved image using a plurality of the captured images.

2. The imaging device of claim 1, 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.

3. The imaging device of claim 2, wherein the spectral filter is selected from the group consisting of an organic color filter, an absorptive material, a dielectric coating, an interference filter, a multilayer coating, and combinations thereof.

4. The imaging device of claim 2, wherein at least one of the imagers further comprises a polarizing filter.

5. The imaging device of claim 2, wherein the construction of the lens stack within an imager differs based upon the specific spectral band of light passed by the spectral filter within the imager such that chromatic aberrations are reduced.

6. The imaging device of claim 5, wherein the prescription of at least one surface of the lens stack within an imager is a function of the specific spectral band of light passed by the spectral filter within the imager.

7. The imaging device of claim 6, wherein the at least one surface of the lens stack is configured so that the back focal length of each lens stack in the imager array are the same independent of the spectral band.

8. The imaging device of claim 2, wherein a combination of high and low Abbe number materials is used in the construction of each of the lens stacks to reduce chromatic aberrations.

9. The imaging device of claim 2, wherein each lens stack includes at least one aperture stop positioned in front of the light sensing element, and the spectral filter is positioned in proximity to the aperture stop.

10. The imaging device of claim 9, wherein the at least one aperture stop is formed by a light blocking material selected from the group consisting of metal materials, oxide materials, black particle filled photoresists and combinations thereof.

11. The imaging device of claim 2, wherein:

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.

12. The imaging device of claim 11, wherein the radii of curvature of the lens surfaces differ based upon the specific spectral band of light passed by the spectral filter within the imager.

13. The imaging device of claim 11, wherein the lens stacks of each of the imagers have the same back focal length.

14. The imaging device of claim 1, wherein the light sensing elements are disposed to detect an image in a backside imaging mode.

15. The imaging device of claim 14, wherein a separate negative lens element is disposed in close proximity to the light sensing elements of an imager and in optical alignment with the lens stack of the imager so that the field curvature of the lens stack is corrected.

16. The imaging device of claim 1, wherein a separate negative lens element is disposed in close proximity to the light sensing elements of an imager and in optical alignment with the lens stack of the imager so that the field curvature of the lens stack is corrected.

17. The imaging device of claim 1, wherein at least two of the imagers in the imager array have different fields of view so that different scene sizes can be captured by the imagers.

18. The imaging device of claim 17, wherein the lens stacks of the at least two imagers have different focal lengths.

19. The imaging device of claim 17, wherein the light sensing elements in each of at least two imagers have different sizes.

20. The imaging device of claim 17, wherein the at least two imagers include different numbers of light sensing elements.

21. The imaging device of claim 1, further comprising a mechanical zoom mechanism within the lens stack of an imager for smoothly transitioning between different fields of view.

22. The imaging device of claim 1, wherein at least one of the imagers is designed to image light in the near-infrared spectrum.

23. The imaging device of claim 1, wherein at least one imager is configured to take a measurement of the visible light spectrum, and wherein the control circuitry is

configured to use said measurement to control the imaging characteristics of the other imagers in said imaging device.

24. The imaging device of claim 1, wherein the imaging device includes at least two camera arrays.

25. The imaging device of claim 24, wherein the at least two camera arrays operate in conjunction during imaging to provide stereo images.

26. The imaging device of claim 24, wherein the at least two camera arrays are spatially separated one from the other in at least one plane.

27. The imaging device of claim 24, wherein each of the camera arrays comprise a different combination of imagers each combination of imagers having different imaging characteristics.

28. The imaging device of claim 1, wherein at least one camera array comprises an N x M array of imagers, where at least one of N and M is greater than 2, and each of said imagers comprising at least two light sensing elements.

29. The imaging device of claim 1, wherein the control circuitry is configured to control the imaging characteristics of each imager.

30. The imaging device of claim 29, wherein the controllable imaging characteristics include exposure time, gain, and black level offset.

31. The imaging device of claim 1, wherein the control circuitry is configured to trigger each of said imagers in accordance with a desired sequence.

32. The imaging device of claim 31, wherein the control circuitry operates the imagers in a staggered sequence.

33. The imaging device of claim 1, wherein:

an initial master setting for the imaging characteristics of each imager is set by the control circuitry;

predefined deviations from the initial master settings are also set by the control circuitry; and

the deviations include functions selected from the group consisting of ISO settings, high dynamic range, gain settings, integration time settings, exposure settings, digital processing settings and combinations thereof.

34. The imaging device of claim 1, wherein the camera arrays are fabricated using techniques consisting of wafer level optics techniques, injection molding, glass molding and combinations thereof.

35. The imaging device of claim 1, wherein each of the plurality of imagers are optically separated from each other.

36. The imaging device of claim 35, 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.

37. The imaging device of claim 35, wherein the imagers are optically separated from each other by opaque walls disposed at the boundaries between the imagers.

38. The imaging device of claim 37, wherein the opaque walls are cavities between the imagers filled with light blocking material.

39. The imaging device of claim 35, wherein:

the lens stack includes spacers; and

the spacers are constructed from an opaque material.

40. The imaging device of claim 35, wherein:

the lens stack includes spacers; and

the spacers are coated with an opaque material.

41. The imaging device of claim 1, wherein the control circuitry is configured to perform normalization of a captured low resolution image using a one dimensional space filling curve to describe a normalization plane.

42. The imaging device of claim 41, wherein the one dimensional space filling curve is expressed as the coefficients of a polynomial.

43. The imaging device of claim 1, wherein the control circuitry is configured to capture multiple low resolution images using different imagers having different exposure times.

44. The imaging device of claim 43, wherein the light sensing elements of at least one of the imagers used to capture an image are high dynamic range light sensing elements.

45. The imaging device of claim 44, wherein at least one of the imagers used to capture a low resolution image is configured to capture a near-IR low resolution image.

46. The imaging device of claim 1, wherein the super-resolution module is configured to generate a depth map for the super-resolution image.

47. The imaging device of claim 46, wherein the super-resolution module is configured to select at least one distance as a focal plane and to apply blurring to pixels with depths that are not proximate a focal plane.

48. The imaging device of claim 1, wherein the super-resolution processing module is configured to perform temperature normalization with respect to the captured images.

49. The imaging device of claim 48, wherein:

the point spread functions of the lens stacks vary with temperature; and

the super-resolution processing module is configured to perform temperature normalization by selecting a point spread functions from temperature calibration data corresponding to the point spread functions of the lens stacks during the capture of the images.

50. The imaging device of claim 1, wherein the super-resolution processing module is configured to computationally correct color differences between the captured images.

51. The imaging device of claim 1, wherein the super-resolution processing module is configured to computationally correct geometric distortion differences between the captured images.

52. A lens stack array, comprising:

lens elements formed on substrates separated by spacers, where the lens elements, substrates and spacers are configured to form a plurality of optical channels;

at least one aperture located within each optical channel;

at least one spectral filter located within each optical channel, where each spectral filter is configured to pass a specific spectral band of light; and

light blocking materials located within the lens stack array to optically isolate the optical channels.

53. The lens stack array of claim 52, wherein the light blocking materials are selected from the group consisting of opaque materials, reflective materials and combinations thereof.

54. The lens stack array of claim 52, wherein:

spectral filters that pass different spectral bands are provided within at least two of the imagers.

55. The lens stack array of claim 54, wherein each spectral filter is selected from the group consisting of an organic color filter, an absorptive material, a dielectric coating, an interference filter, a multilayer coating, and combinations thereof.

56. The lens stack array of claim 54, further comprising at least one polarizing filter located within each optical channel.

57. The lens stack array of claim 54, wherein the construction of each optical channel differs based upon the specific spectral band of light passed by the spectral filter within the imager so that chromatic aberrations are reduced.

58. The lens stack array of claim 54, wherein the prescription of at least one surface of a lens within each optical channel is a function of the specific spectral band of light passed by the spectral filter within the optical channel.

59. The lens stack array of claim 58, wherein the back focal lengths of each optical channel in the lens stack array are the same irrespective of the spectral band of light passed by the spectral filter within the optical channel.

60. The lens stack array of claim 54, wherein a combination of high and low Abbe number materials is used in the construction of each of the lens elements in an optical channel to reduce chromatic aberrations.

61. The lens stack array of claim 54, further comprising:

at least one aperture stop located within each optical channel;

wherein each spectral filter is located within each optical channel so that the spectral filter is proximate the aperture stop.

62. The lens stack array of claim 61, wherein each aperture stop is formed by a light blocking material selected from the group consisting of metal materials, oxide materials, black particle filled photoresists and combinations thereof.

63. The lens stack array of claim 54, wherein:

the at least one lens surface of a lens in each optical channel differs based upon the specific spectral band of light passed by the spectral filter within the optical channel; and

each lens surface is selected from the group consisting of diffractive, Fresnel, refractive and combinations thereof.

64. The lens stack array of claim 63, wherein the radii of curvature of the lens surfaces differ based upon the specific spectral band of light passed by the spectral filter within the optical channel.

65. The lens stack array of claim 63, wherein each of the optical channels have the same back focal length.

66. The lens stack array of claim 52, wherein at least one of the lens elements in an optical channel is a negative lens element, and the negative lens element is proximate the image formed by the optical channel.

67. The lens stack array of claim 52, wherein at least two of the optical channels have different focal lengths.

68. The lens stack array of claim 52, further comprising a mechanical zoom mechanism within an optical channel configured to smoothly transition between different fields of view.

69. The lens stack array of claim 52, wherein the lens stack array comprises an N x M array of optical channels, where at least one of N and M is greater than 2.

70. The lens stack array of claim 52, wherein the lens stack array is fabricated using techniques consisting of wafer level optics techniques, injection molding, glass molding and combinations thereof.

71. The lens stack array of claim 52, wherein the light blocking materials located within the lens stack array to optically separate the optical channels comprise at least two opaque surfaces located on a substrate within an optical channel, where the two opaque surfaces have openings arranged in axial alignment with the optical channel.

72. The lens stack array of claim 52, wherein the light blocking materials located within the lens stack array to optically separate the optical channels comprise opaque walls disposed at the boundaries between the optical channels.

73. The lens stack array of claim 72, wherein the opaque walls are cavities between the optical channels filled with light blocking material.

74. The lens stack array of claim 52, wherein a plurality of the spacers are constructed from light blocking materials and are located within the lens stack array to optically separate the optical channels.

75. The lens stack array of claim 52, wherein a plurality of the spacers are coated in light blocking materials and are located within the lens stack array to optically isolate the optical channels.

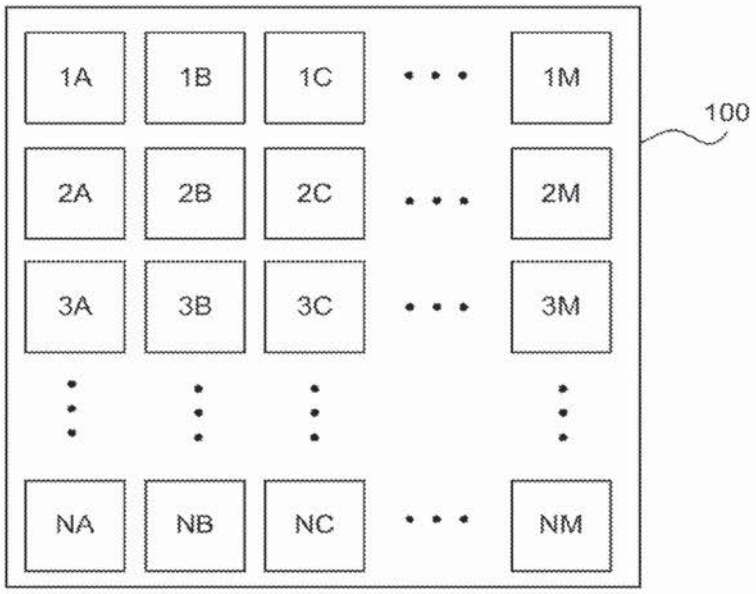

1A
1B
1C
1M
2A
2B
2C
2M
3A
3B
3C
3M
NA
NB
NC
NM
100

FIG. 1

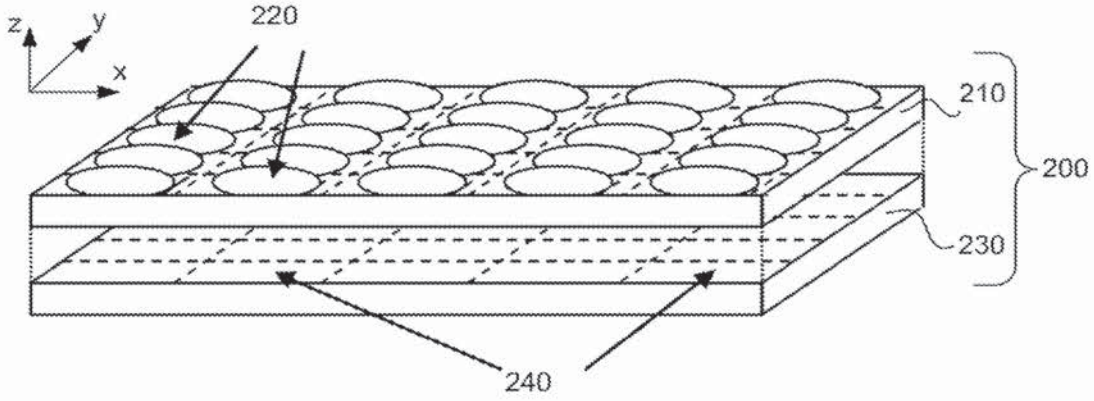

z
y
x
220
210
200
230
240

FIG. 2A

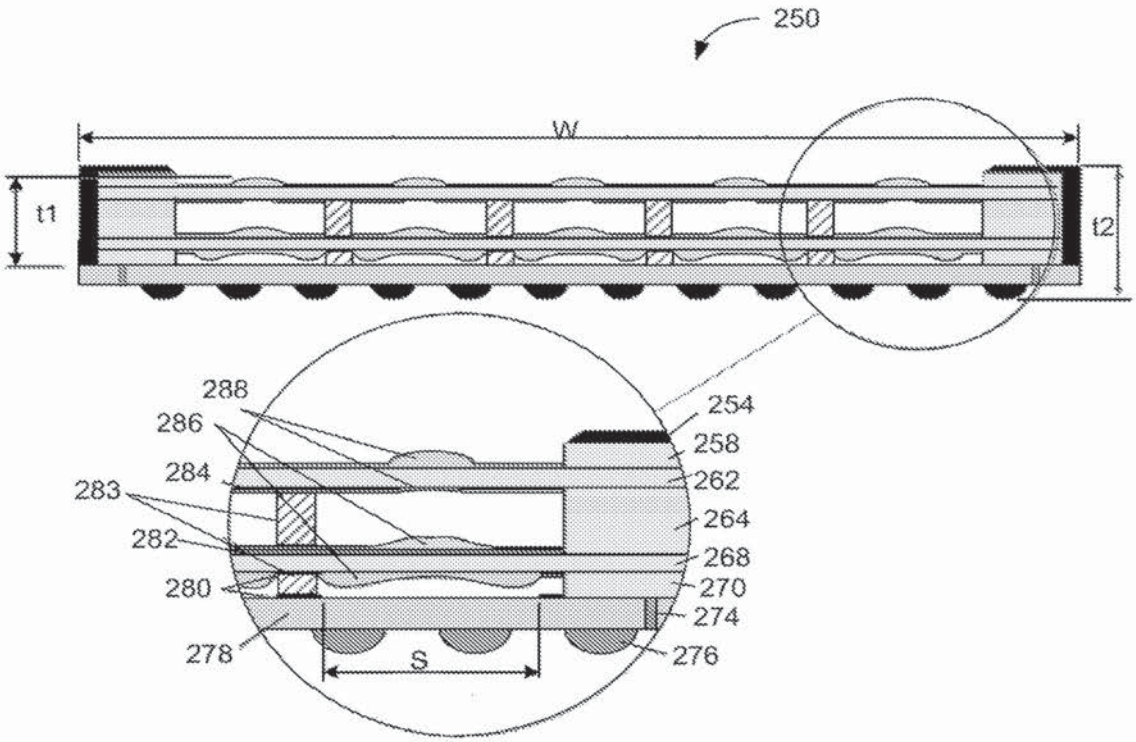


FIG. 2B

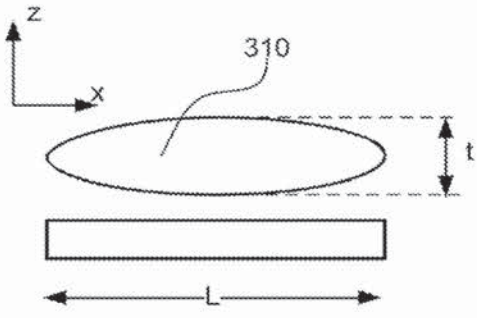


FIG. 3A

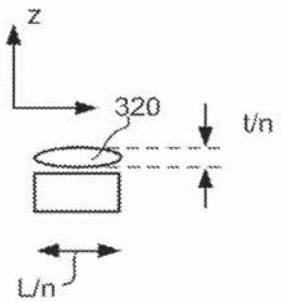


FIG. 3B

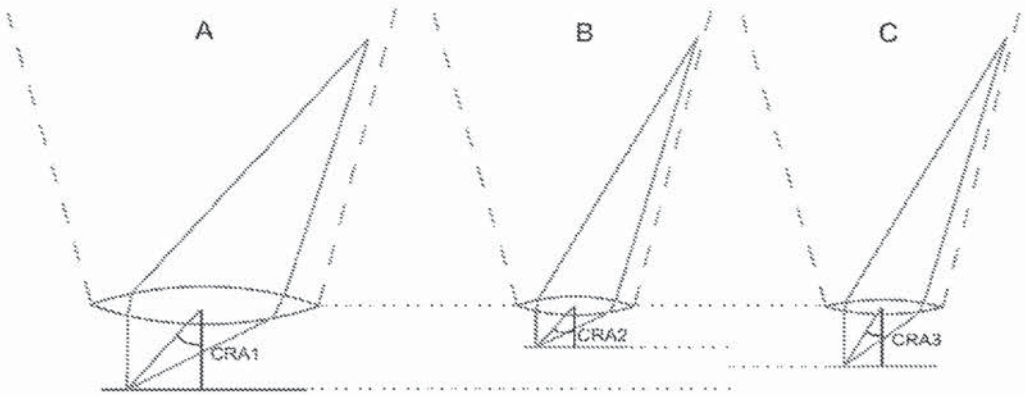

A
B
C
CRA1
CRA2
CRA3

FIG. 3C

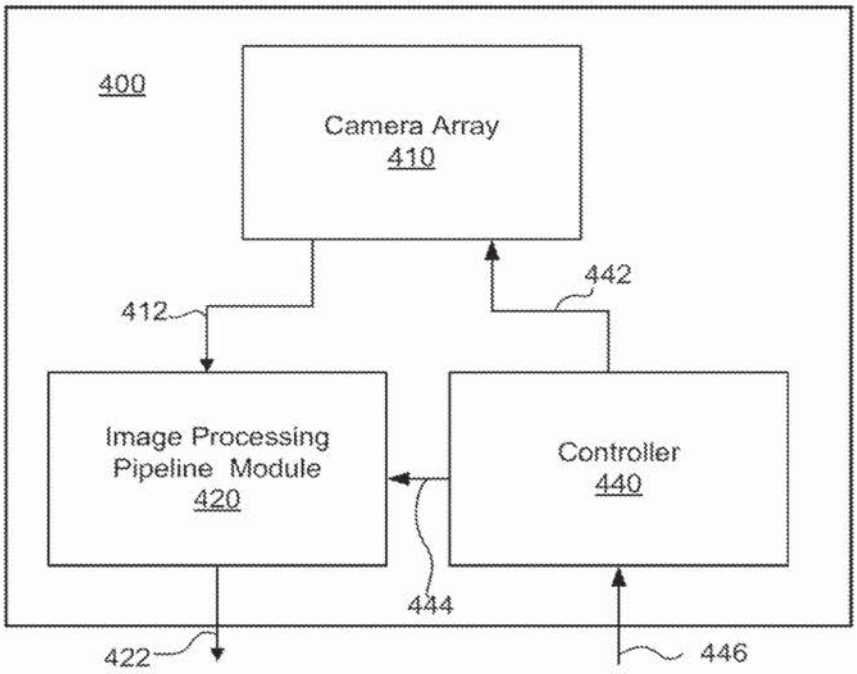

400
Camera Array
410
412
442
Image Processing
Pipeline Module
420
Controller
440
444
422
446

FIG. 4

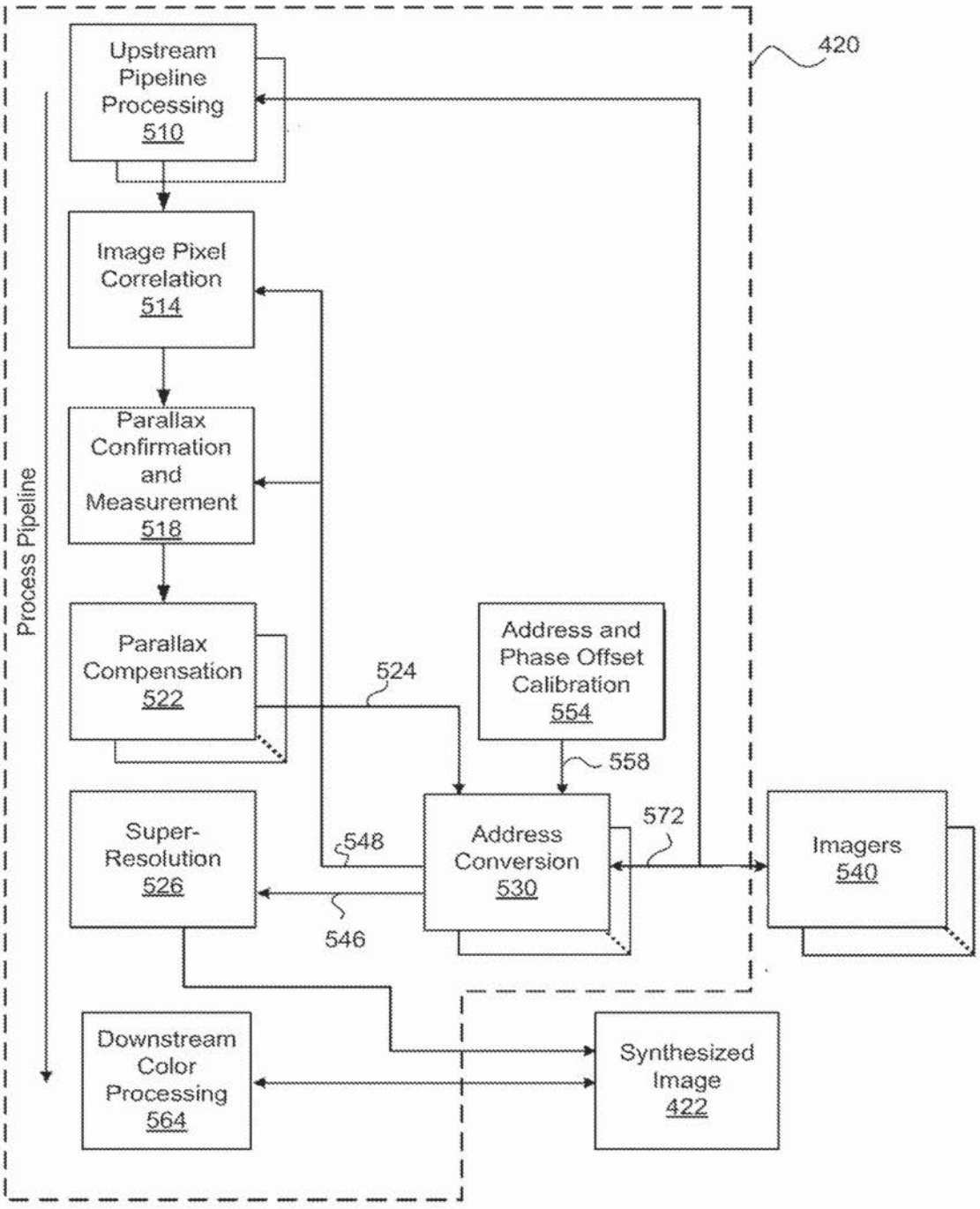

420
Upstream Pipeline Processing 510
Image Pixel Correlation 514
Parallax Confirmation and Measurement 518
Parallax Compensation 522
524
Address and Phase Offset Calibration 554
558
Super-Resolution 526
548
Address Conversion 530
572
Imagers 540
546
Process Pipeline
Downstream Color Processing 564
Synthesized Image 422

FIG. 5

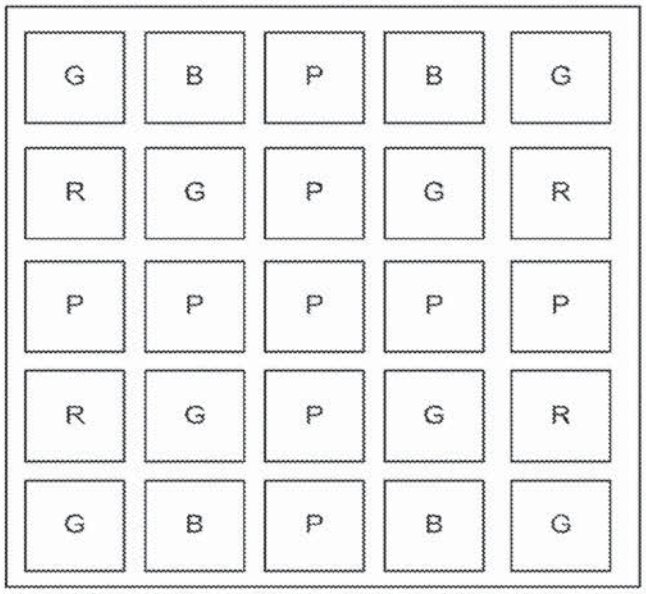


FIG. 6A


G R G R G
B G B G B
G R G R G
B G B G B
G R G R G

FIG. 6B

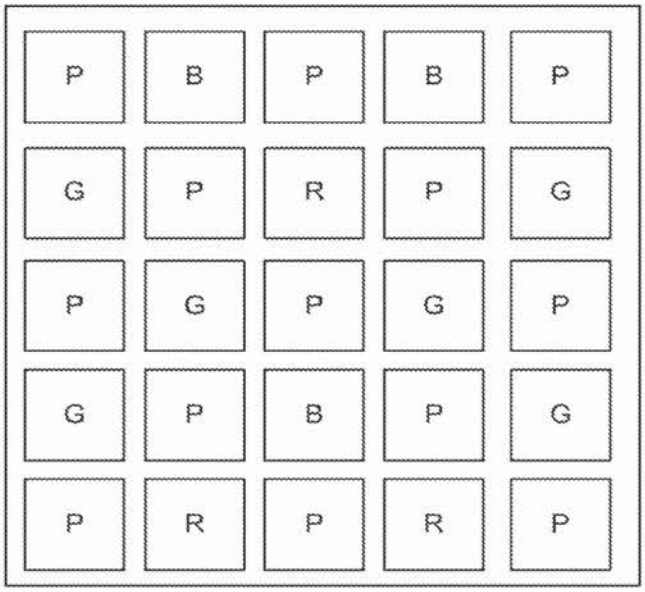

P B P B P
G P R P G
P G P G P
G P B P G
P R P R P

FIG. 6C

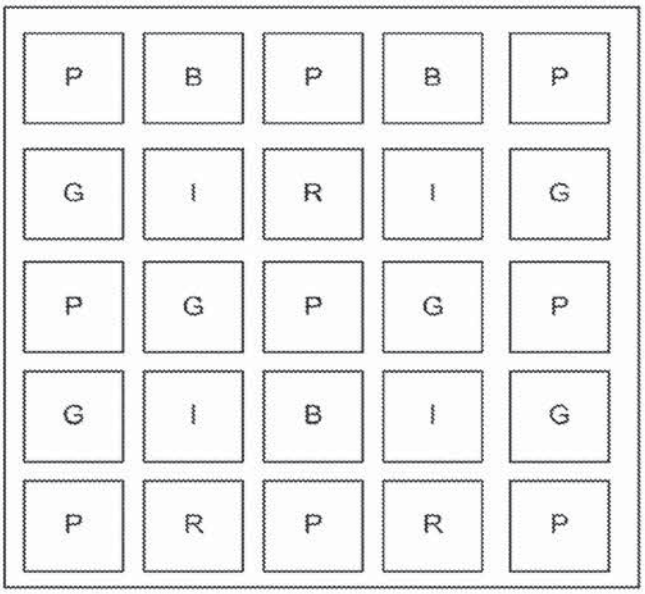

P B P B P
G I R I G
P G P G P
G I B I G
P R P R P

FIG. 6D

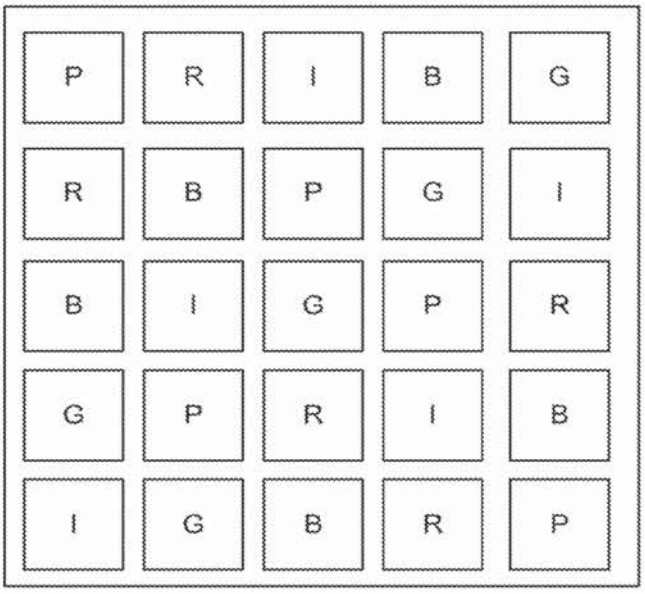

P R I B G
R B P G I
B I G P R
G P R I B
I G B R P

FIG. 6E

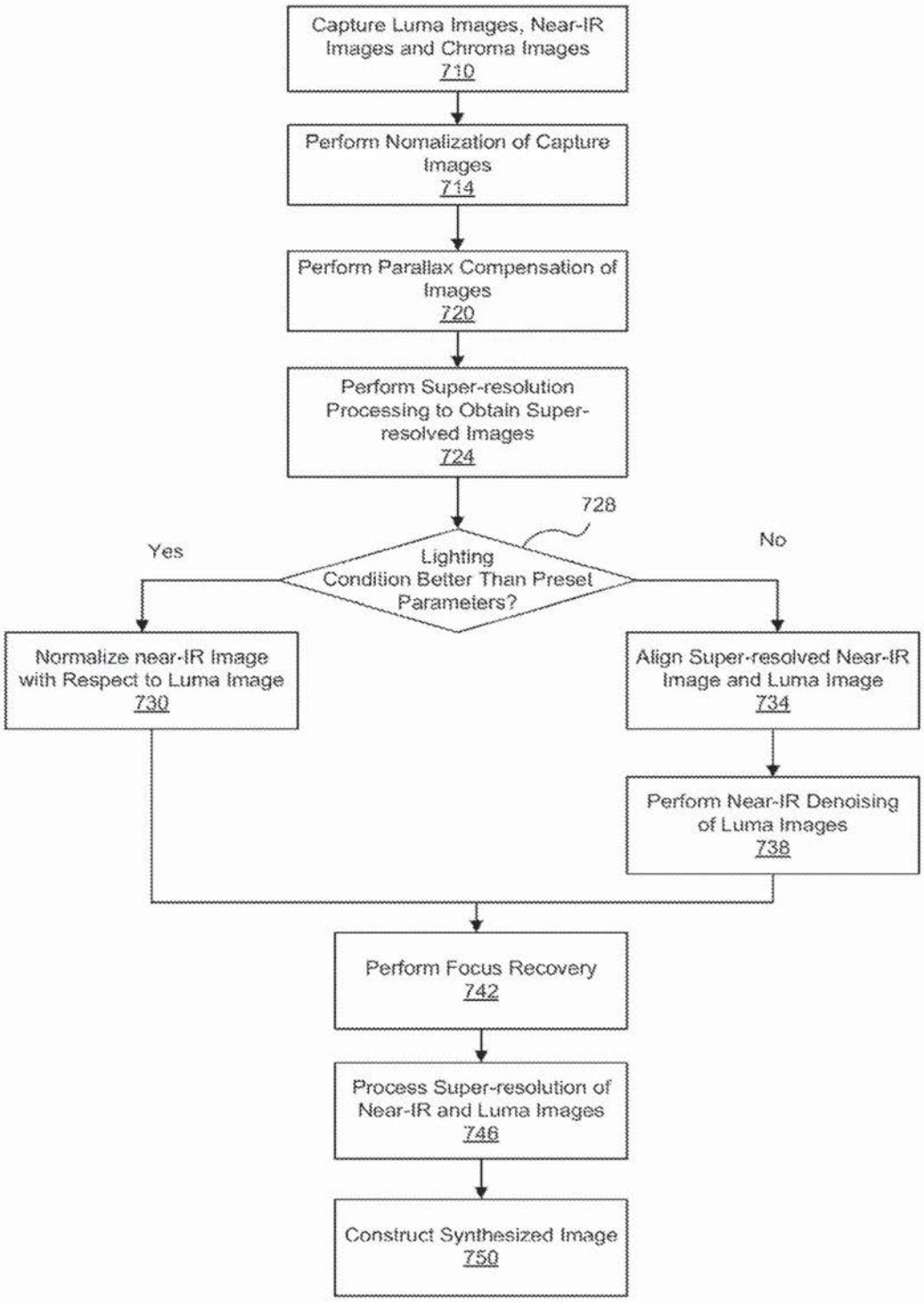

Capture Luma Images, Near-IR Images and Chroma Images
710
Perform Nomalization of Capture Images
714
Perform Parallax Compensation of Images
720
Perform Super-resolution Processing to Obtain Super-resolved Images
724
728
Lighting Condition Better Than Preset Parameters?
Yes
No
Normalize near-IR Image with Respect to Luma Image
730
Align Super-resolved Near-IR Image and Luma Image
734
Perform Near-IR Denoising of Luma Images
738
Perform Focus Recovery
742
Process Super-resolution of Near-IR and Luma Images
746
Construct Synthesized Image
750

FIG. 7

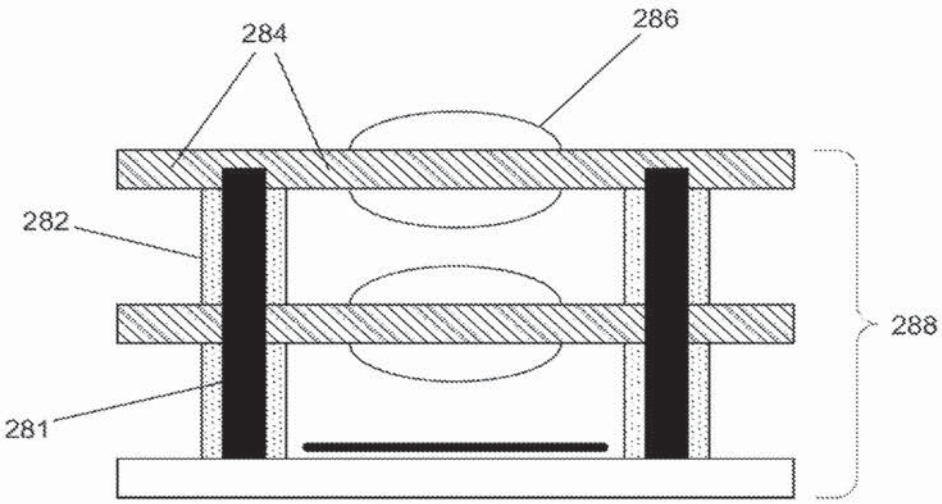


FIG. 2C

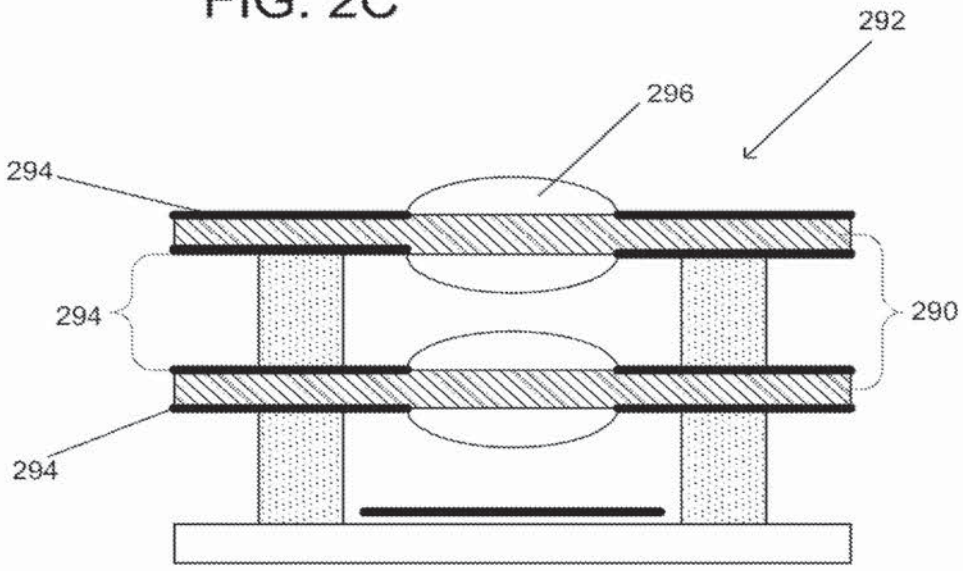


FIG. 2D

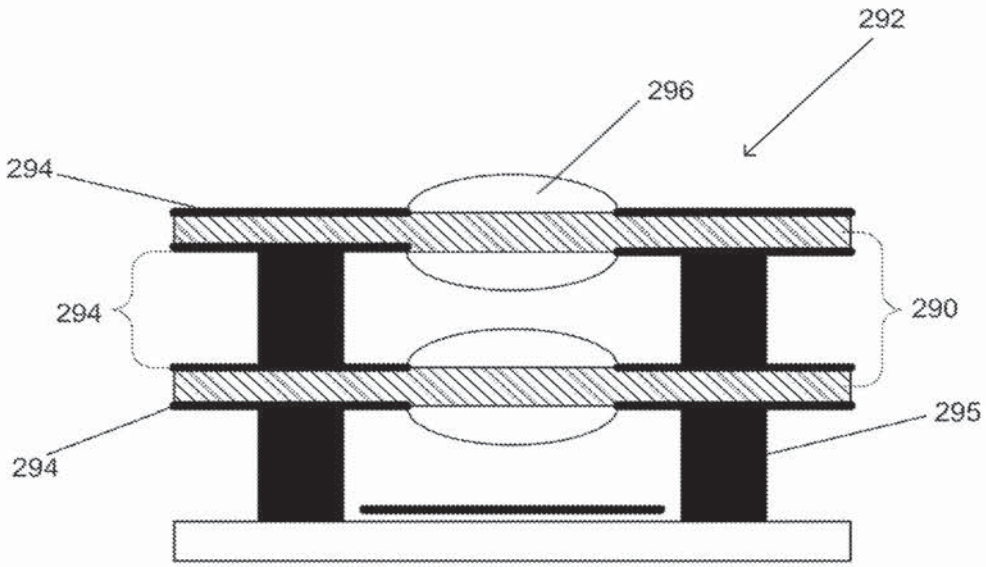


FIG. 2E

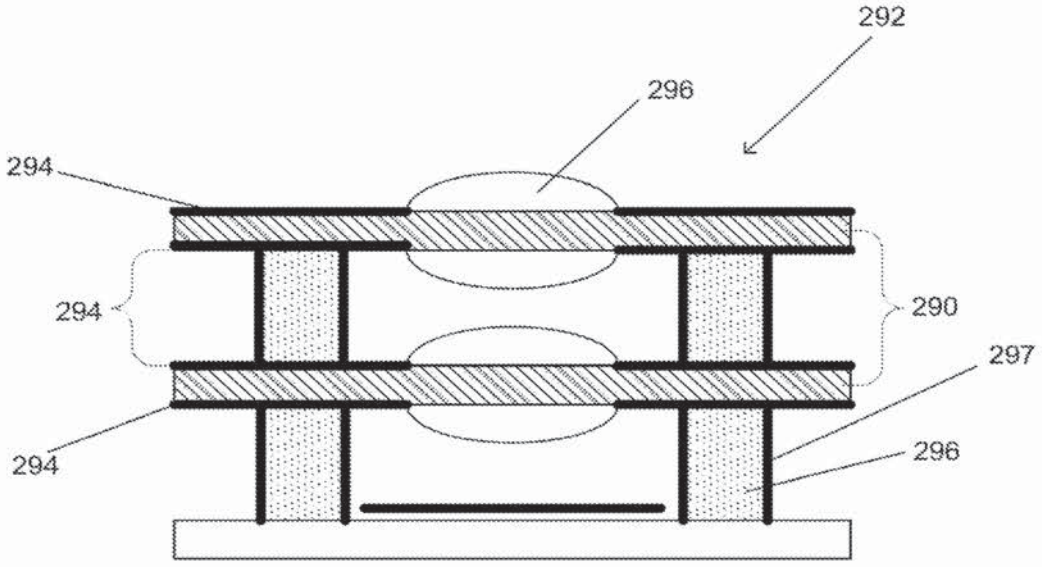


FIG. 2F

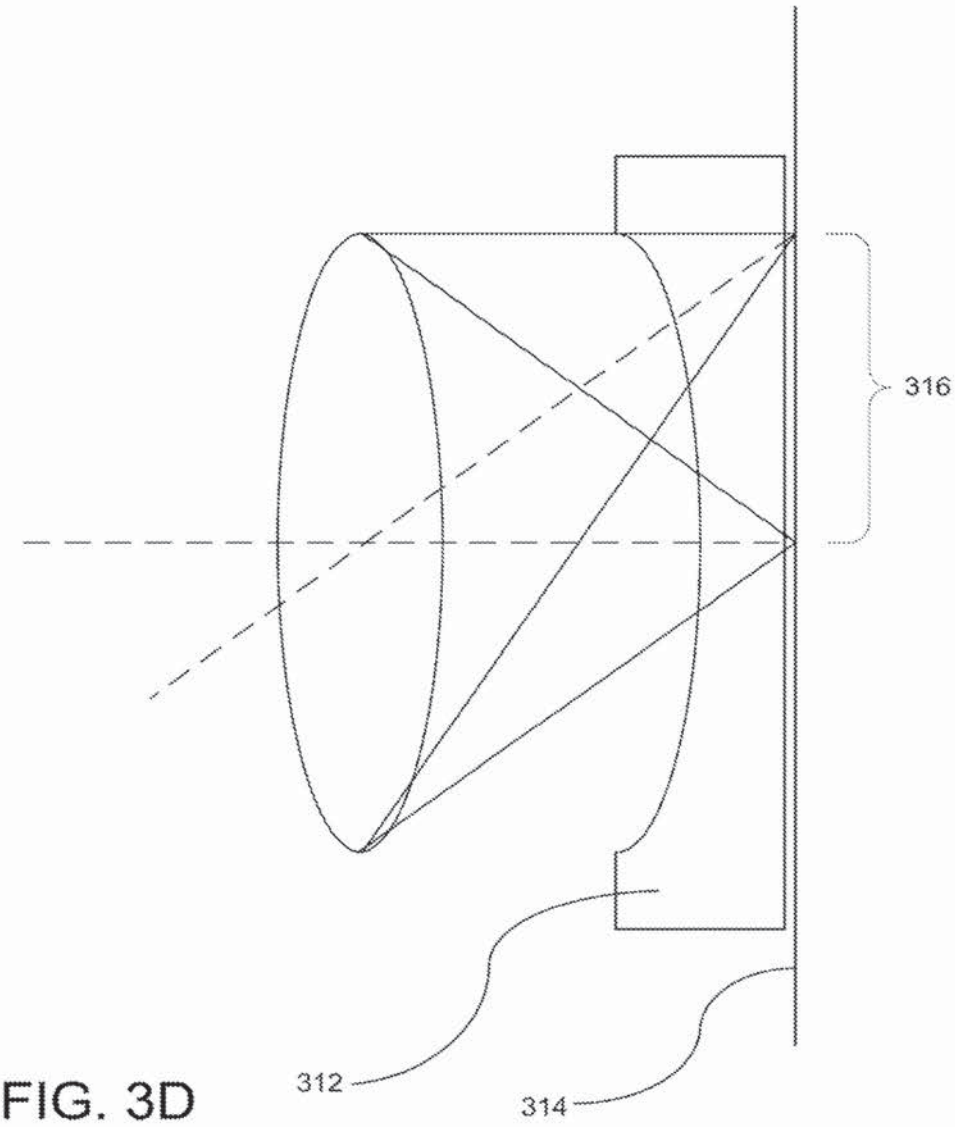


FIG. 3D


G B G B G
R G G G R
G G G G G
R G G G R
G B G B G

FIG. 6F

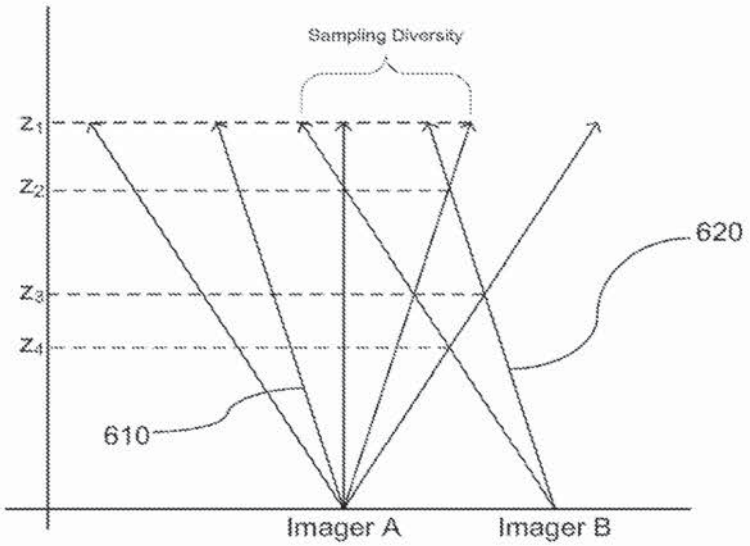

Sampling Diversity
z1
z2
z3
z4
620
610
Imager A
Imager B

FIG. 6G

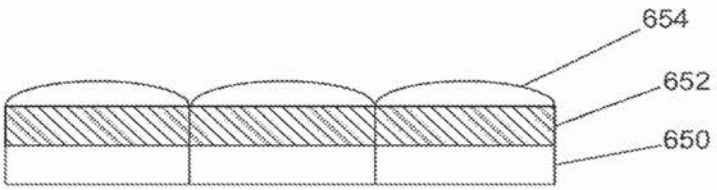


FIG. 6H

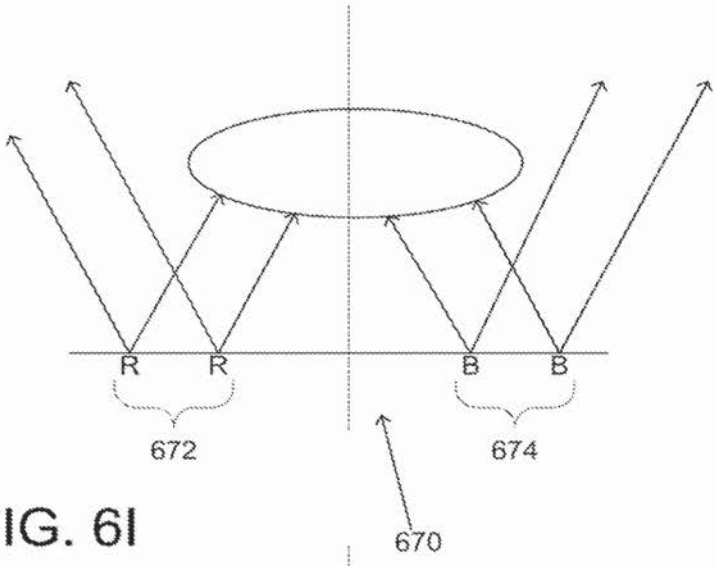


FIG. 6I

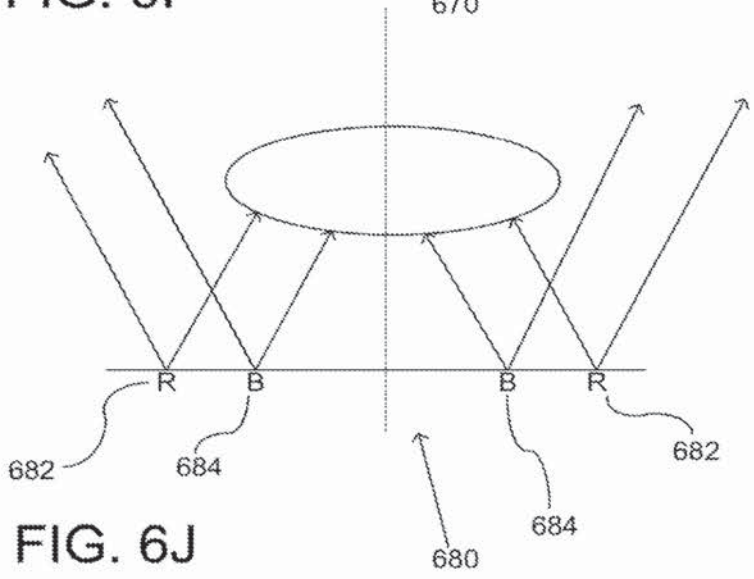


FIG. 6J

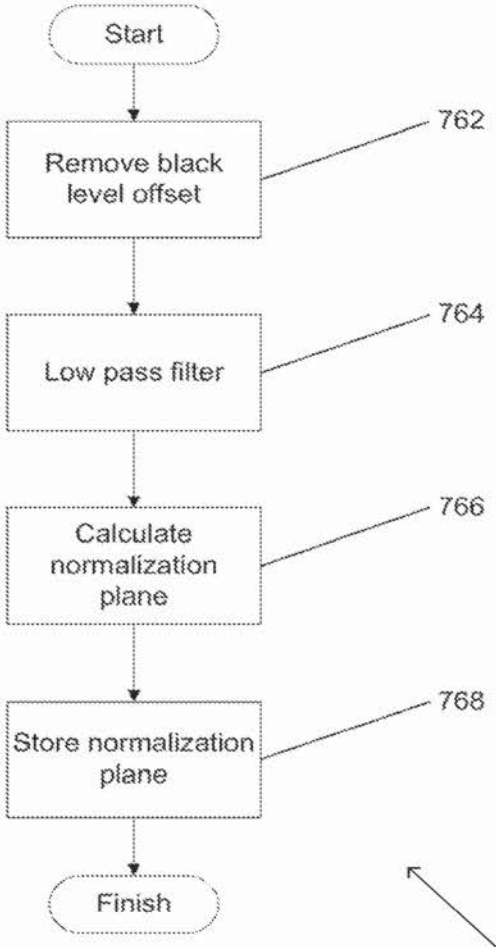

Start
Remove black level offset
762
Low pass filter
764
Calculate normalization plane
766
Store normalization plane
768
Finish
760

FIG. 7A

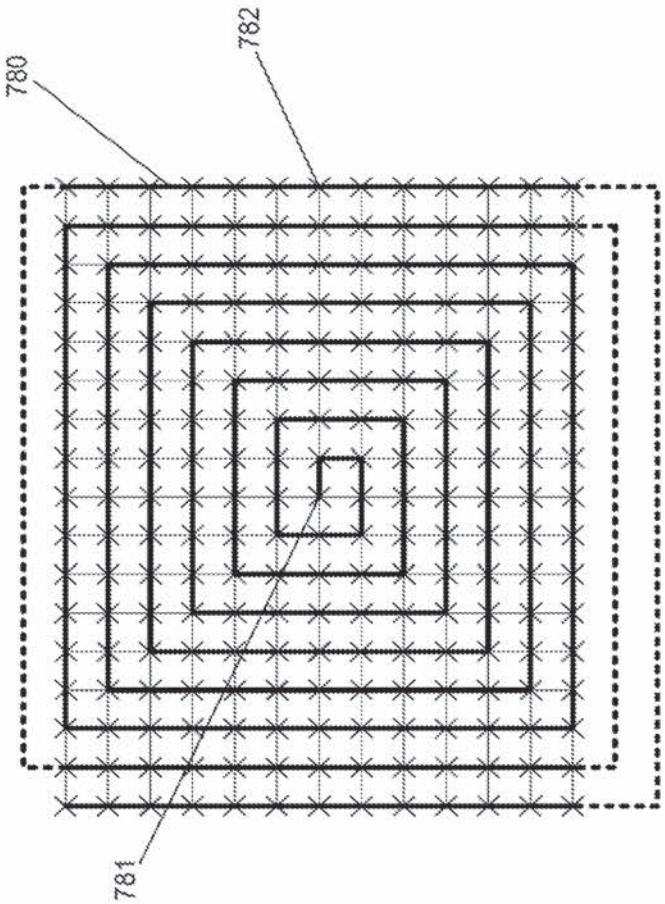


FIG. 7B

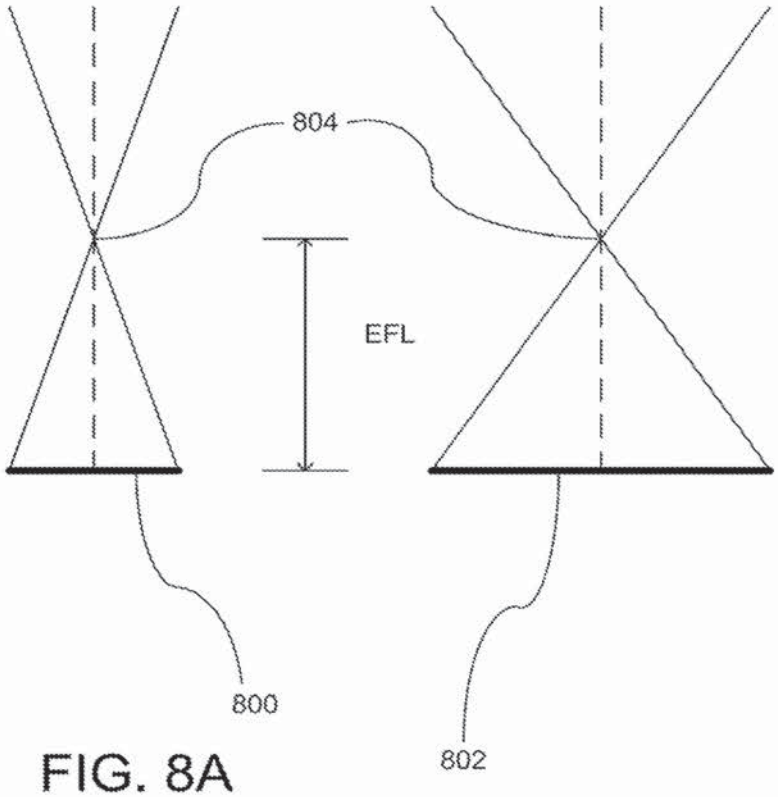


FIG. 8A

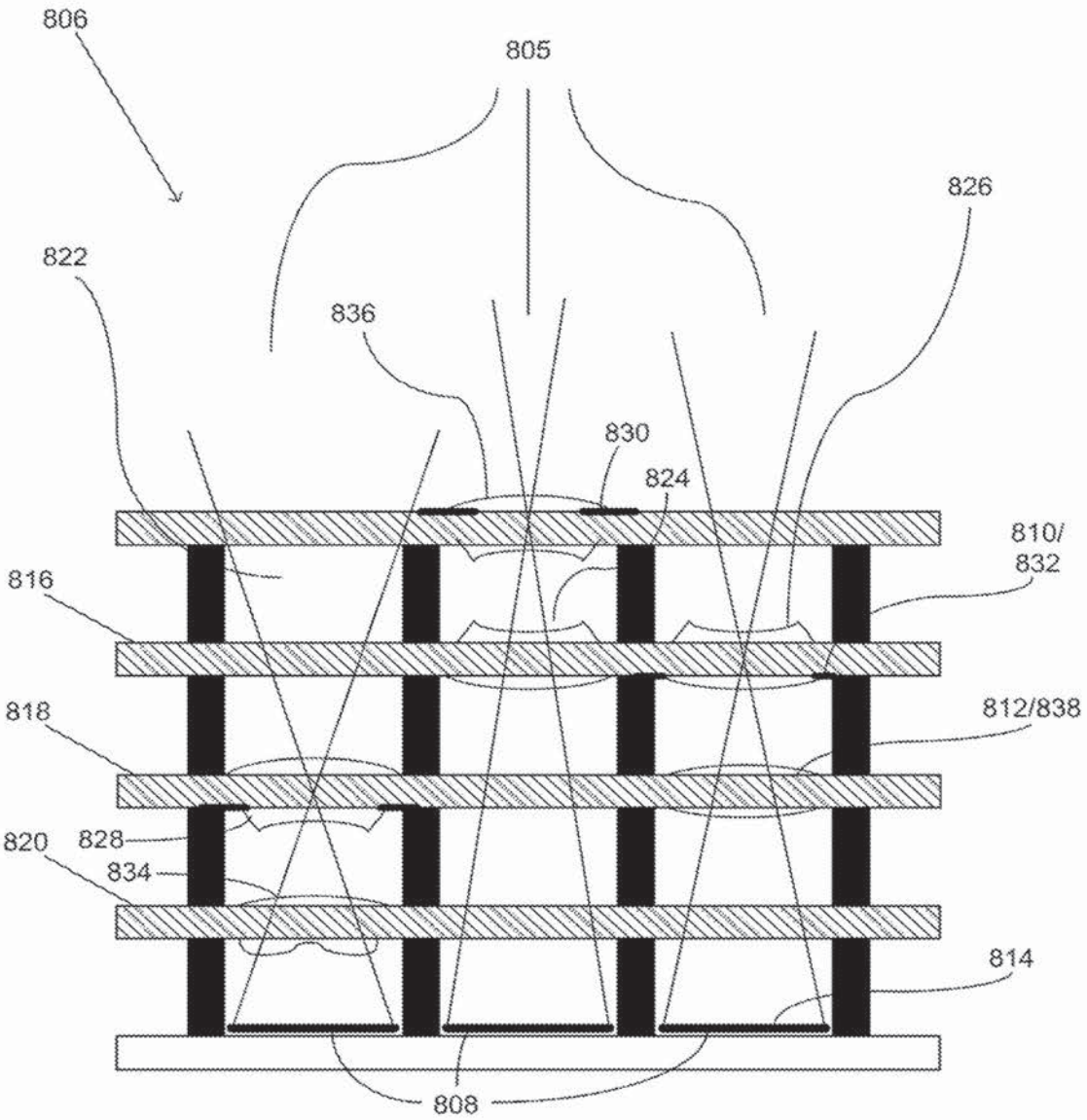

806
805
826
822
836
830
824
810/
832
816
818
812/838
820
828
834
814
808

FIG. 8B

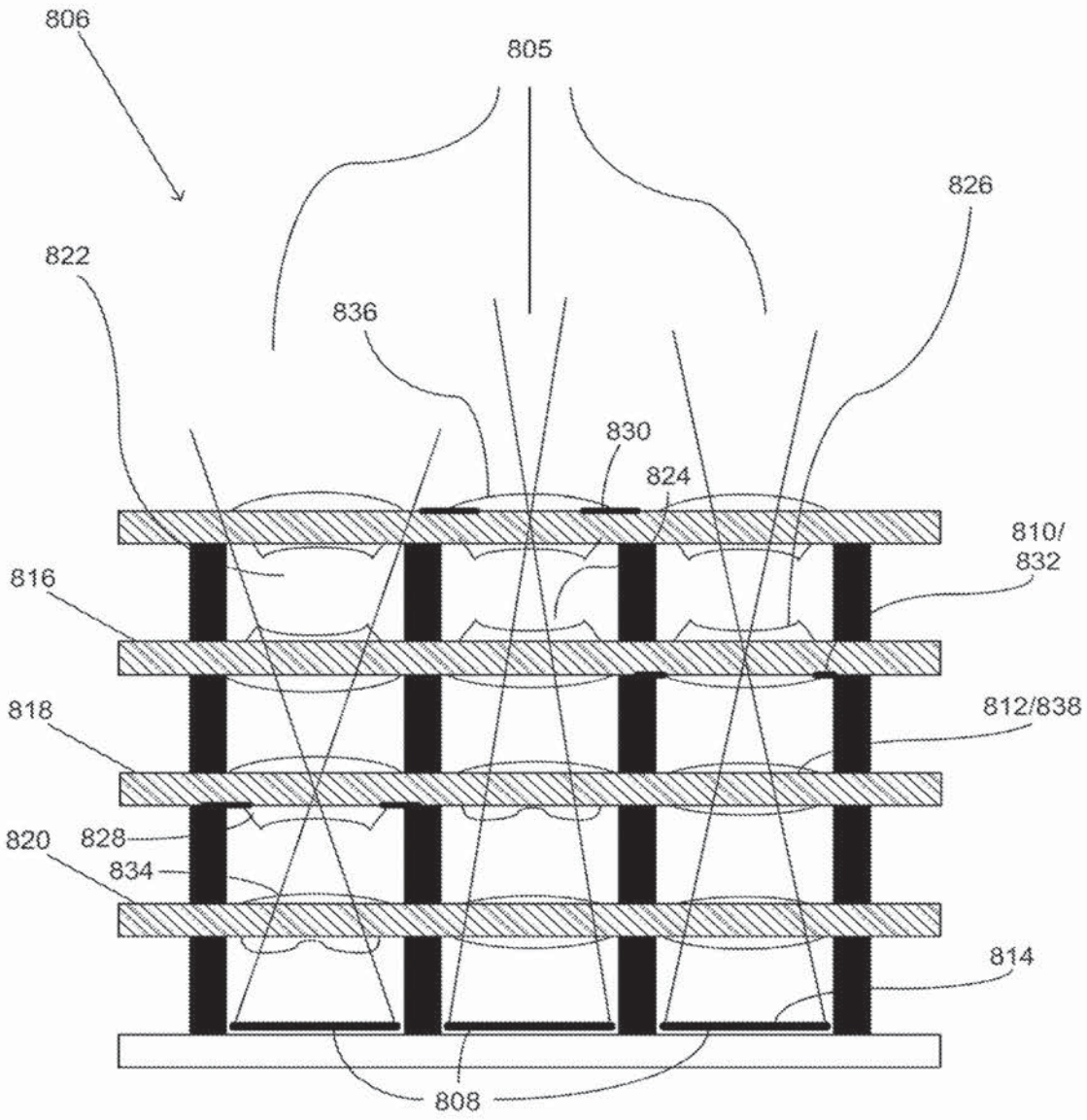

806
805
826
822
836
830
824
810/
832
816
818
812/838
820
828
834
814
808

FIG. 8C

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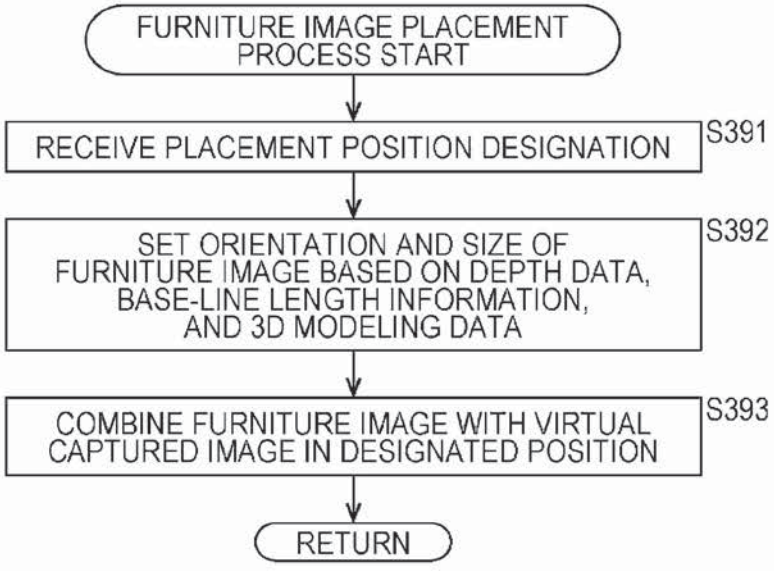
[Continued on next page]

WO 2015/037211 A1

(54) Title: IMAGE PROCESSING DEVICE AND METHOD

(57) Abstract: An image processing apparatus including circuitry configured to initiate a setting of an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object.

FIG. 34



(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, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, KM, ML, MR, NE, SN, TD, TG).

Published:

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

Description

Title of Invention: IMAGE PROCESSING DEVICE AND METHOD

Technical Field

[0001] The present disclosure relates to image processing devices and methods, and more particularly, relates to an image processing device and a method that are designed to increase the user-friendliness of a service that uses multiview images.

[0002] <CROSS REFERENCE TO RELATED APPLICATIONS>

This application claims the benefit of Japanese Priority Patent Applications JP 2013-188409 filed on September 11, 2013 and JP 2014-174173 filed on August 28, 2014, the entire contents of which are incorporated herein by reference.

Background Art

[0003] There is a known technique to measure distances to a measuring object (a subject) by using images with different viewpoints. For example, a distance calculation method that uses a technique called "stereo matching" has been suggested (see Patent Document 1, for example).

[0004] With the stereo matching technique, depth data that indicates a distance to a subject in a multiview image is calculated from the multiview image formed with images having different viewpoints from one another. With the depth data, multiview images are superimposed on one another to generate an image to be provided to a user.

Citation List

Patent Literature

[0005] PTL 1: JP 2011-171858 A

Summary of Invention

Technical Problem

[0006] However, there is a demand for an increase in user-friendliness of such a multiview-image using service.

[0007] The present disclosure is made in view of those circumstances, and is to increase the user-friendliness of the service that uses multiview images.

Solution to Problem

[0008] An image processing apparatus according to an embodiment of the present technique includes circuitry configured to initiate a setting of an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object.

[0009] An image processing method according to an embodiment includes: setting an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object; and placing the set object to be displayed at the position within the background image.

[0010] An image processing device according to an embodiment of the present technique includes an object placement unit that sets the orientation and the size of an object in a position in which the object is to be placed in a background image, and places the object having the set orientation and the set size in the designated position in the background image, the orientation and the size being set based on depth data, base-line length information, and the three-dimensional modeling data of the object, the depth data indicating the distance to a subject in the background image, the base-line length information being information indicating a reference length in the background image.

[0011] When another position is designated after the object is placed in the background image, the object placement unit may set the orientation and the size of the object in the another position, and place the object having the set orientation and the set size in the another position in the background image.

[0012] When there is a change in the position or the orientation of the viewpoint of the background image, the object placement unit may set the orientation and the size of the object in the position in which the object was placed before the change in the position or the orientation of the viewpoint in the background image not yet having the change in the position or the orientation of the viewpoint, and place the object having the set orientation and the size in the position in which the object was placed before the change in the position or the orientation of the viewpoint in the background image having the change in the position or the orientation of the viewpoint.

[0013] The object placement unit may move the object, to bring the object having the set orientation and the set size into contact with the floor.

[0014] The object placement unit may measure the length of a designated area in the background image.

[0015] The object placement unit may simulate lighting in the background image based on light source parameters and the depth data, and cause the background image to reflect the simulated lighting, the light source parameters being parameters related to the light source.

[0016] The object placement unit may identify a portion that satisfies line-of-flow conditions in the background image having the object placed therein, and emphasize the identified portion in the background image having the object placed therein.

[0017] The object placement unit may set the orientation and the size of a person in a

position in which an image of the person is to be placed in a background having the object placed therein, and place the image of the person having the set orientation and the set size in the designated position in the background image having the object placed therein, the orientation and the size of the person being set based on the depth data, the base-line length information, and the three-dimensional modeling data of the image of the person.

[0018] The object placement unit may set the orientation and the size of the object selected from candidates for the object in the position in which the object selected from the candidates for the object is to be placed in the background image, and place the object selected from the candidates for the object having the set orientation and the set size in the designated position in the background image, the orientation and the size of the selected object being set based on the depth data, the base-line length information, and the three-dimensional modeling data of the object selected from the candidates for the object.

[0019] The object placement unit may identify objects that can be placed in the background image, and select the object to be placed in the background image from the identified objects, the objects being identified based on the depth data, the base-line length information, and the three-dimensional modeling data.

[0020] The image processing device may further include: an imaging unit that captures an image of the subject, and obtains the captured image as the background image; and a depth data generation unit that generates the depth data of the captured image obtained by the imaging unit.

[0021] The captured image may be a multiview image formed with images having different viewpoints from one another, the depth data generation unit may generate the depth data of the multiview image, and the image processing device may further include a virtual captured image generation unit that generates a virtual captured image as the background image based on the multiview image and the depth data, the virtual captured image being obtained by imaging the subject of the multiview image.

[0022] The object may be an image of furniture.

[0023] The image processing device may further include a purchase processing unit that performs a purchase process to purchase the furniture that is placed in the background image by the object placement unit.

[0024] The image processing device may further include a transmission unit that transmits multiview image data as the data of a multiview image and the depth data of the multiview image, the multiview image being formed with images having different viewpoints from one another and used for generating the background image.

[0025] The image processing device may further include a combined image data generation unit that generates the image data of the background image having the object placed

therein by the object placement unit. The transmission unit may further transmit the combined image data generated by the combined image data generation unit.

[0026] The image processing device may further include an application parameter generation unit that generates application parameters that are parameters related to combining of the background image and the object. The transmission unit may further transmit the application parameters generated by the application parameter generation unit.

[0027] The image processing device may further include a metadata generation unit that generates metadata about the multiview image. The transmission unit may further transmit the metadata generated by the metadata generation unit.

[0028] The metadata may include the base-line length information.

[0029] An image processing method according to an embodiment of the present technique includes: setting the orientation and the size of an object in a position in which the object is to be placed in a background image, the orientation and the size being set based on depth data, base-line length information, and the three-dimensional modeling data of the object, the depth data indicating the distance to a subject in the background image, the base-line length information being information indicating a reference length in the background image; and placing the object having the set orientation and the set size in the designated position in the background image.

[0030] In an embodiment of the present technique, the orientation and the size of an object in a position in which the object is to be placed in a background image are set based on depth data indicating the distance to a subject in the background image, base-line length information indicating a reference length in the background image, and the three-dimensional modeling data of the object. The object having the set orientation and the set size is then placed in the designated position in the background image.

Advantageous Effects of Invention

[0031] According to an embodiment of the present technique, images can be processed. According to an embodiment of the present technique, the user-friendliness of a service that uses multiview images can also be increased.

Brief Description of Drawings

[0032] [fig.1]Fig. 1 is a diagram for explaining an example of a multiview-image using service platform.

[fig.2]Fig. 2 is a diagram for explaining an example of an application that uses multiview images.

[fig.3]Fig. 3 is a diagram showing a typical example structure of a multiview-image using service providing system.

[fig.4]Fig. 4 is a block diagram showing a typical example structure of the terminal

device.

[fig.5]Fig. 5 is a diagram for explaining the outline of the imaging unit.

[fig.6]Fig. 6 is a diagram showing a typical example structure of the server.

[fig.7]Fig. 7 is a functional block diagram for explaining the functions of the terminal device and the server.

[fig.8]Fig. 8 is a diagram showing an example of the information being managed by the server.

[fig.9]Fig. 9 is a flowchart showing an example flow of a multiview-image using service providing process.

[fig.10]Fig. 10 is a diagram showing an example of a multiview image and depth data.

[fig.11]Fig. 11 is a diagram showing a typical example structure of a multiview image file.

[fig.12]Fig. 12 is a diagram for explaining an example of a camera array.

[fig.13]Fig. 13 is a diagram for explaining an example of metadata.

[fig.14]Fig. 14 is a flowchart for explaining an example flow of a depth detection process.

[fig.15]Fig. 15 is a diagram showing another typical example structure of a multiview-image using service providing system.

[fig.16]Fig. 16 is a diagram showing a typical example structure of the application providing server.

[fig.17]Fig. 17 is a functional block diagram for explaining the functions of the terminal device, the server, and the application providing server.

[fig.18]Fig. 18 is a flowchart showing another example flow of a multiview-image using service providing process.

[fig.19]Fig. 19 is a diagram showing examples of displayed information.

[fig.20]Fig. 20 is a diagram showing yet another typical example structure of a multiview-image using service providing system.

[fig.21]Fig. 21 is a diagram for explaining an example flow of virtual lens processing.

[fig.22]Fig. 22 is a functional block diagram for explaining the functions of the terminal device and the server.

[fig.23]Fig. 23 is a flowchart showing yet another example flow of a multiview-image using service providing process.

[fig.24]Fig. 24 is a diagram for explaining an example of virtual lens selection.

[fig.25]Fig. 25 is a flowchart for explaining an example flow of the virtual lens processing.

[fig.26]Fig. 26 is a diagram for explaining an example of a lens profile.

[fig.27]Fig. 27 is a diagram showing yet another typical example structure of a multiview-image using service providing system.

[fig.28]Fig. 28 is a diagram for explaining an example furniture layout.

[fig.29]Fig. 29 is a diagram for explaining another example layout.

[fig.30]Fig. 30 is a functional block diagram for explaining the functions of the terminal device, the server, and the furniture sales server.

[fig.31]Fig. 31 is a flowchart showing yet another example flow of a multiview-image using service providing process.

[fig.32]Fig. 32 is a flowchart showing yet another example flow of a multiview-image using service providing process, continued from Fig. 31.

[fig.33]Fig. 33 is a flowchart showing yet another example flow of a multiview-image using service providing process, continued from Fig. 32.

[fig.34]Fig. 34 is a flowchart for explaining an example flow of a furniture image placement process.

[fig.35]Fig. 35 is a diagram showing examples of furniture layout updates.

[fig.36]Fig. 36 is a flowchart for explaining an example flow of a furniture placement updating process.

[fig.37]Fig. 37 is a diagram for explaining an example of floor contact determination.

[fig.38]Fig. 38 is a flowchart for explaining an example flow of a floor contact determination process.

[fig.39]Fig. 39 is a diagram for explaining an example of measurement.

[fig.40]Fig. 40 is a flowchart for explaining an example flow of a measurement process.

[fig.41]Fig. 41 is a diagram for explaining an example of a lighting simulation.

[fig.42]Fig. 42 is a flowchart for explaining an example flow of a lighting process.

[fig.43]Fig. 43 is a diagram for explaining an example of presentation of a line of flow.

[fig.44]Fig. 44 is a flowchart for explaining an example flow of a line-of-flow presentation process.

[fig.45]Fig. 45 is a diagram for explaining an example of human image placement.

[fig.46]Fig. 46 is a flowchart for explaining an example flow of a human image placement process.

[fig.47]Fig. 47 is a flowchart for explaining an example flow of a furniture list restriction process.

Description of Embodiments

[0033] The following is a description of modes for embodying this disclosure (hereinafter referred to as the embodiments). Explanation will be made in the following order.

1. First Embodiment (Multiview-Image Using Service Platform)
2. Second Embodiment (Management of Multiview Images)
3. Third Embodiment (Application Sales)

4. Fourth Embodiment (Virtual Lens Processing)

5. Fifth Embodiment (Sales Support)

6. Others

[0034] <1. First Embodiment>

<Multiview-Image Using Service Platform>

Fig. 1 is a diagram for explaining an example of a multiview-image using service platform. The multiview-image using service platform 100 shown in Fig. 1 is a basic structure/environment that provides a user with services using multiview images each formed with images having different viewpoints. The multiview-image using service platform 100 has functions such as a cloud storage 101 and an application market 102.

[0035] The cloud storage 101 is a service that stores and manages multiview image data 111 that is data of multiview images. For example, a user who is registered in the multiview-image using service platform operates a multiview imaging device 121 to capture images of a subject, and obtains captured images with difference viewpoints as a multiview image. The user then operates the multiview imaging device 121 to supply the multiview image data to the multiview-image using service platform 100. The cloud storage 101 stores the supplied multiview image data, and manages the multiview image data for the user.

[0036] Based on the multiview image data and the like, the cloud storage 101 can also generate data related to the multiview image data, where necessary. Furthermore, the cloud storage 101 can provide the multiview image data being managed therein to the terminal device being operated by the user or the later described application, in response to a request from the user or the like.

[0037] The application market 102 is a service that performs some processing by using the multiview image data, provides a user with an application 112, sells the application 112 to the user, or executes the application 112. The application 112 is for providing the user with multiview-image using services. This application 112 may be executed by the multiview-image using service platform 100 or by a terminal device.

[0038] As this application 112 is executed, the user is provided with various highly-useful services such as games using multiview images, space combining, lens simulations, space recognitions, and sales supports.

[0039] The services to be provided by the application 112 may be of any kinds as long as they use multiview images. For example, a lens simulation is a service that simulates a virtual optical system, and generates a virtual image of a subject captured by the virtual optical system, using a multiview image. In that case, the application 112 sets a virtual lens 150 as shown in Fig. 2A, and simulates a ray vector 151 that is light incident on the virtual lens 150 from the subject, a ray vector 152 that is the incident light after passing through the virtual lens 150, a virtual image sensor 153 that obtains a virtual

captured image from the ray vector 152, and the like. Based on the above simulations, the application 112 generates a virtual captured image from a multiview image, and provides the user with the virtual captured image. The application 112 can also select or sell the virtual lens 150 that is set in the above manner, for example.

[0040] Through a lens simulation, a virtual lens can be set. Accordingly, an optical system of any type can be simulated. That is, through a lens simulation, an actual optical system or an unrealistic optical system can be simulated. As such a service is provided, the user can reproduce captured images obtained with various kinds of optical systems. For example, through such a lens simulation, the user can readily obtain an image captured with an optical system having a larger aperture than that of an optical system that obtains the respective captured images forming a multiview image. Also, through such a lens simulation, the user can more readily obtain an image with higher resolution than that of the respective images forming a multiview image, an image with a wide field of view, an image with a narrow field of view and a long focal length, or the like. Furthermore, through such a lens simulation, it is possible to readily obtain an image captured with a high-grade lens or an image captured with an unrealistic optical system, for example. In other words, the user can obtain various kinds of captured images at low costs.

[0041] A sales support is a service to support product sales by using multiview images, for example. Any products may be sold, and any measures may be taken to provide the support. For example, in this service, the product to be sold may be furniture, and images of furniture may be virtually arranged in a captured image as shown in Fig. 2B. In this case, the application 112 generates a captured image by superimposing the respective captured images of a multiview image on one another, arranges the images of furniture in the captured image by using three-dimensional modeling data (also referred to as 3D modeling data) and depth data indicating the distances to the subject in the multiview image, and provides the user with the combined image. The application 112 also sets the positions of the pieces of furniture to be arranged based on an operation of the user.

[0042] By virtue of such a service, the user can capture an image of his/her own room, and arrange images of furniture in desired positions in the captured image (or the image of his/her own room). Accordingly, the user can accurately assume the layout prior to the purchase. Specifically, through such a service, the user can reduce the pre-purchase anxiety that "the purchased furniture might be too big for my room", "the purchased furniture might not fit in my room", or the like. Accordingly, the user can be motivated to purchase. In this manner, the application 112 can support furniture sales.

[0043] As described above, the multiview-image using service platform 100 can not only generate and provide an image from a multiview image, but also manage data related

to the user and multiview images, sell applications, and provide services using applications. Accordingly, various services that are very useful to the user can be provided. That is, the multiview-image using service platform 100 can increase the user-friendliness of the multiview-image using service.

[0044] Although a multiview image is formed with captured images in the above description, the number of images forming a multiview image is not fixed. Also, some or all of the images forming a multiview image may be unrealistic, or each of the images may be partially or entirely unrealistic like an artificially-drawn computer graphic image (that is, a multiview image may include an image that is not a captured image).

[0045] Also, the terminal device to which the multiview-image using service platform 100 is to provide services may be the multiview imaging device 121 being operated by the user owning a multiview image, may be a terminal device other than the multiview imaging device 121 being operated by the user, or may be a terminal device being operated by another user authorized to use the multiview image by the user.

[0046] Further, the multiview-image using service platform 100 may have any physical structure. For example, the multiview-image using service platform 100 may be formed with one server, or may be formed with more than one server. Also, some or all of the functions of the multiview-image using service platform 100 may be shared with other devices over a network, and be executed in cooperation with the other devices over a network, to realize a cloud computing structure. Furthermore, some or all of the functions of the multiview-image using service platform 100 may be executed by a terminal device.

[0047] Examples of services to be provided by the multiview-image using service platform 100 are described below in detail.

[0048] <2. Second Embodiment>

<Management of Multiview Images>

As described above in the first embodiment, the multiview-image using service platform 100 has the function of the cloud storage 101, and can provide a service to store and manage multiview image data. In this embodiment, the management of multiview images is described.

[0049] <Multiview-Image Using Service Providing System>

Fig. 3 is a diagram showing a typical example structure of a multiview-image using service providing system. The multiview-image using service providing system 200 shown in Fig. 3 is an example of a system to which the present technique is applied. In this system, a server 202 provides a multiview-image using service to a terminal device 201 connected thereto via a network 210. That is, the multiview-image using service providing system 200 is an example of a structure that realizes the multiview-image using service platform 100.

[0050] Fig. 3 shows an example of a structure related to the provision of a service related to management of multiview images among the services to be provided by the multiview-image using service platform 100. In Fig. 3, the multiview-image using service providing system 200 includes the terminal device 201 and the server 202 that are connected to the network 210.

[0051] The network 210 is a network such as the Internet or a local area network. The network 210 is formed with one or more wired and/or wireless networks. The terminal device 201 and the server 202 are connected to the network 210 in a wired or wireless manner.

[0052] The terminal device 201 captures images of a subject to perform multiview imaging and obtain a multiview image that is formed with captured images having different viewpoints from one another. The terminal device 201 then encodes the multiview image data, to generate multiview encoded data. The terminal device 201 transmits the generated multiview encoded data to the server 202.

[0053] The server 202 manages users that are registered in advance. The server 202 also acquires the transmitted multiview image encoded data, and detects the depth of the multiview image, to generate depth data. The server 202 further turns the data related to the multiview image into a file, to generate a multiview image file. The server 202 stores (saves) the generated multiview image file, and manages the stored file. The multiview image file being managed by the server 202 is provided to the terminal device 201 or an application to be executed, where necessary.

[0054] <Terminal Device>

Fig. 4 is a block diagram showing a typical example structure of the terminal device 201. As shown in Fig. 4, in the terminal device 201, a CPU (Central Processing Unit) 221, a ROM (Read Only Memory) 222, and a RAM (Random Access Memory) 223 are connected to one another via a bus 224.

[0055] An input/output interface 230 is also connected to the bus 224. An input unit 231, an output unit 232, a storage unit 233, a communication unit 234, and a drive 235 are connected to the input/output interface 230.

[0056] The input unit 231 is formed with an input device that receives external information such as a user input. The input unit 231 includes operation buttons, a touch panel, a microphone, and an input terminal, for example. The input unit 231 may also include various kinds of sensors, such as an acceleration sensor, an optical sensor, and a temperature sensor. The output unit 232 is formed with an output device that outputs information such as images and sound. The output unit 232 includes a display, a speaker, and an output terminal, for example.

[0057] The storage unit 233 is formed with a hard disk, a RAM disk, a nonvolatile memory, or the like. The communication unit 234 is formed with a network interface, for

example. The drive 235 drives a removable medium 241 such as a magnetic disk, an optical disk, a magnetooptical disk, or a semiconductor memory.

[0058] The CPU 221 performs various kinds of processes by loading a program stored in the storage unit 233 into the RAM 223 via the input/output interface 230 and the bus 224, and executing the program. Necessary data for the CPU 221 to perform various kinds of processes and the like are also stored in the RAM 223 as appropriate.

[0059] The program to be executed by the CPU 221 can be recorded on the removable medium 241 as a packaged medium, for example, and be provided to the terminal device 201. In this case, the program can be installed into the storage unit 233 via the input/output interface 230 when the removable medium 241 is mounted in the drive 235.

[0060] Alternatively, the program can be provided to the terminal device 201 via a wired or wireless transmission medium such as a LAN, the Internet, or digital satellite broadcasting. In this case, the program can also be received by the communication unit 234 via a wired or wireless transmission medium, and be installed into the storage unit 233.

[0061] Also, the program can be installed in the ROM 222 or the storage unit 233 in advance.

[0062] An imaging unit 236 is further connected to the input/output interface 230. Under the control of the CPU 221, for example, the imaging unit 236 captures images of a subject to perform multiview imaging and obtain a multiview image formed with captured images having different viewpoints from one another. The imaging unit 236 includes camera modules 242-1 through 242-N. N is an integer that is 2 or greater. The camera modules 242-1 through 242-N have the same structures as one another, and perform the same processes as one another. Hereinafter, the cameral modules 242-1 through 242-N will be referred to simply as the camera modules 242, as long as there is no need to distinguish them from one another.

[0063] The camera modules 242 are modules that include optical systems having image sensors (imaging elements), and obtain captured images by capturing images of a subject. The respective camera modules 242 are arranged in different positions from one another on a flat surface or a curved surface, such as positions C11, C12, C13, C21, C22, C23, C31, C32, and C33 shown in Fig. 5. That is, the camera modules 242-1 through 242-N capture images of a subject, and obtain captured images having different viewpoints from one another.

[0064] Under the control of the CPU 221, for example, the imaging unit 236 captures images of a subject by using the camera modules 242-1 through 242-N, and obtains N (more than one)captured images having different viewpoints from one another. The imaging unit 236 obtains the captured images as a multiview image (multiview image

data). That is, the imaging unit 236 performs multiview imaging by using the camera modules 242.

[0065] Under the control of the CPU 221, for example, the imaging unit 236 supplies the obtained multiview image data to the CPU 221 and the RAM 223 via the input/output interface 230, the bus 224, and the like, supplies and stores the obtained multiview image data into the storage unit 233 via the input/output interface 230, supplies the obtained multiview image data to the output unit 232 to output the multiview image data, or supplies the obtained multiview image data to the communication unit 234 to supply the multiview image data to the outside.

[0066] The angles of view and the imaging directions of the respective camera modules 242 may or may not be the same as one another. For example, in one of the camera modules 242, the angle of view and/or the imaging direction may differ from those of the other camera modules 242. Alternatively, the angles of view and the imaging directions of all the camera modules 242 may differ from one another. However, as will be described later, multiview captured images are to be superimposed on one another to generate an image. Therefore, at least some portions of the imaging ranges of the respective camera modules 242 (or the subject of the respective camera modules 242) preferably overlap with one another.

[0067] In multiview imaging, imaging conditions, such as the imaging timing, the exposure, and the aperture value, may or may not be the same among the camera modules 242. Also, the multiview image (or the respective captured images forming a multiview image) obtained by multiview imaging may be a still image or may be a moving image.

[0068] The imaging unit 236 may be provided as one component on the housing of the terminal device 201 at the time of the manufacture thereof, or may be designed as a module that is independent of the terminal device 201 but can be connected to the terminal device 201. For example, the imaging unit 236 may be an external component that is connected to an external terminal of the terminal device 201 and operates under the control of the terminal device 201. Further, the imaging unit 236 may be a device that is independent of the terminal device 201. For example, the imaging unit 236 may be an imaging device such as a camera that is independent of the terminal device 201, be connected to the terminal device 201 by a wired or wireless communication, and supply a multiview image obtained by multiview imaging to the terminal device 201.

[0069] <Server>

Fig. 6 is a block diagram showing a typical example structure of the server 202. As shown in Fig. 6, in the server 202, a CPU 251, a ROM 252, and a RAM 253 are connected to one another via a bus 254.

[0070] An input/output interface 260 is also connected to the bus 254. An input unit 261, an

output unit 262, a storage unit 263, a communication unit 264, and a drive 265 are connected to the input/output interface 260.

[0071] The input unit 261 is formed with an input device that receives external information such as a user input. The input unit 261 includes operation buttons, a touch panel, a microphone, a camera, and an input terminal, for example. The input unit 261 may also include various kinds of sensors, such as an acceleration sensor, an optical sensor, and a temperature sensor. The output unit 262 is formed with an output device that outputs information such as images and sound. The output unit 262 includes a display, a speaker, and an output terminal, for example.

[0072] The storage unit 263 is formed with a hard disk, a RAM disk, a nonvolatile memory, or the like. The communication unit 264 is formed with a network interface, for example. The drive 265 drives a removable medium 271 such as a magnetic disk, an optical disk, a magnetooptical disk, or a semiconductor memory.

[0073] The CPU 251 performs various kinds of processes by loading a program stored in the storage unit 263 into the RAM 253 via the input/output interface 260 and the bus 254, and executing the program. Necessary data for the CPU 251 to perform various kinds of processes and the like are also stored in the RAM 253 as appropriate.

[0074] The program to be executed by the CPU 251 can be recorded on the removable medium 271 as a packaged medium, for example, and be provided to the server 202. In this case, the program can be installed into the storage unit 263 via the input/output interface 260 when the removable medium 271 is mounted in the drive 265.

[0075] Alternatively, the program can be provided to the server 202 via a wired or wireless transmission medium such as a LAN, the Internet, or digital satellite broadcasting. In this case, the program can also be received by the communication unit 264 via a wired or wireless transmission medium, and be installed into the storage unit 263.

[0076] Also, the program can be installed in the ROM 252 or the storage unit 263 in advance.

[0077] <Functional Blocks>

The terminal device 201 has functions shown as functional blocks in Fig. 7A, as the CPU 221 executes a predetermined program. As shown in Fig. 7A, the CPU 221 has functional blocks such as an imaging control unit 281, a metadata generation unit 282, an encoding unit 283, and a transmission control unit 284.

[0078] The imaging control unit 281 performs a process related to multiview imaging control. The metadata generation unit 282 performs a process related to generation of metadata of a multiview image obtained by multiview imaging. The encoding unit 283 performs a process related to encoding of a multiview image. The transmission control unit 284 performs a process related to transmission control for multiview image data and the like.

[0079] Meanwhile, the server 202 has functions shown as functional blocks in Fig. 7B, as the CPU 251 executes a predetermined program. As shown in Fig. 7B, the CPU 251 has functional blocks such as a user management unit 291, an acquisition control unit 292, a depth detection unit 293, a file generation unit 294, and a data management unit 295.

[0080] The user management unit 291 performs a process related to management of users to whom multiview-image using services are to be provided. For each user, the user management unit 291 stores and manages, in the storage unit 263, user management information 301 shown in Fig. 8A, for example. As shown in Fig. 8A, the user management information 301 includes a user ID as the identification information about a user, the past purchases by the user, file management information identification information as the identification information for the file management information associated with the user (or registered with the user), preference setting predictions that are information predictive of the settings preferred by the user based on a statistical analysis or the like, the points (or money) held by the user, comments sent to/from other users, and the like. The user management information 301 may of course include any information. Some of the above described information may be excluded, or information other than the above described information may be included.

[0081] The acquisition control unit 292 performs a process related to control on acquisition of information such as multiview image data and the like transmitted from the terminal device 201. The depth detection unit 293 performs a process related to detection of the depth value of a multiview image. The file generation unit 294 performs a process related to generation of a multiview image file from various kinds of data including multiview image data.

[0082] The data management unit 295 performs a process related to management of data such as a multiview image file. For each multiview image file, the data management unit 295 stores and manages, in the storage unit 263, file management information 302 shown in Fig. 8B, for example. As shown in Fig. 8B, the file management information 302 includes multiview image file identification information that is the identification information for a multiview image file, edit result image identification information that is associated with the multiview image file and is the identification information for an edit result image as the result of editing of a multiview image, application parameter identification information as the identification information for an application parameter that is associated with the multiview image file and is the history of application execution using the multiview image, and the like. The file management information 302 may of course include any information. Some of the above described information may be excluded, or information other than the above described information may be included.

[0083] <Flow of a Multiview-Image Using Service Providing Process>

The terminal device 201 and the server 202 of the multiview-image using service providing system having the above described structure perform a multiview-image using service providing process to provide a service using multiview images, or provide a service such as management of multiview images in this embodiment. Referring now to the flowchart shown in Fig. 9, an example flow of the multiview-image using service providing process to be performed by those devices is described.

[0084] In step S101, the imaging control unit 281 of the terminal device 201 controls the imaging unit 236 to perform multiview imaging on a subject and obtain a multiview image. For example, the imaging control unit 281 performs multiview imaging to obtain a multiview image 311 formed with captured images having different viewpoints from one another as shown in Fig. 10A.

[0085] Referring back to Fig. 9, after multiview image data is obtained by the multiview imaging, the metadata generation unit 282 in step S102 generates metadata of the multiview image data. As will be described later in detail, the metadata include array information indicating the relative positional relationship among the respective viewpoints of the multiview image, and viewpoint number information indicating the number of viewpoints of the multiview image. That is, the metadata generation unit 282 generates metadata including the array information and the viewpoint number information, and associates the multiview image data with the information.

[0086] In step S103, the encoding unit 283 encodes the multiview image data by a predetermined encoding method, to generate multiview image encoded data. The encoding method may be any method, as long as image data is encoded by the method. For example, the encoding method may be an existing encoding method such as JPEG (Joint Photographic Experts Group) or MPEG (Moving Picture Experts Group), or may be a novel encoding method designed for multiview images. After the encoding of the multiview image data, the above described metadata (such as the array information and the viewpoint number information) of the multiview image data is associated with the multiview image encoded data (or is turned into metadata of the multiview image encoded data) by the metadata generation unit 282.

[0087] In step S104, the transmission control unit 284 controls the communication unit 234 to transmit the multiview image encoded data generated in step S103, as well as the metadata generated in step S102, to the server 202. For example, the transmission control unit 284 transmits the multiview image encoded data and the metadata as a bit stream or auxiliary information about a bit stream.

[0088] In step S111, the acquisition control unit 292 of the server 202 controls the communication unit 264, to acquire the multiview image encoded data and its metadata transmitted from the terminal device 201 in step S104.

[0089] In step S112, the depth detection unit 293 decodes the multiview image encoded data acquired in step S111 by a decoding method compatible with the encoding method used in step S103.

[0090] In step S113, the depth detection unit 293 detects the depth of the multiview image to generate depth data, using the multiview image data obtained by decoding the multiview image encoded data in step S112. For example, the depth detection unit 293 generates a depth map 312 as the depth data showing the distances to the subject with degrees of luminance and colors on a pixel-to-pixel basis as shown in Fig. 10B. The depth detection will be described later in detail.

[0091] Referring back to Fig. 9, after generating the depth data, the depth detection unit 293 in step S114 encodes the multiview image data from which the depth has been detected, to generate multiview image encoded data. The encoding method may be any method, as long as image data is encoded by the method. For example, the encoding method may be an existing encoding method such as JPEG or MPEG, or may be a novel encoding method designed for multiview images. The encoding method may or may not be the same as the encoding method used in step S103. The depth detection unit 293 associates the generated depth data with the multiview image encoded data.

[0092] The depth detection (the depth data generation) may be performed in a device other than the server 202. For example, the depth detection may be performed in the terminal device 201. In that case, the CPU 221 of the terminal device 201 further includes the necessary functional block such as the depth detection unit 293 as appropriate. In such a case, the depth detection unit 293 detects a depth prior to the encoding of the multiview image data by the encoding unit 283 (prior to the processing in step S103). In step S103, the encoding unit 283 encodes the multiview image data, as described above. The depth detection unit 293 then associates the depth data with the multiview image encoded data, and the metadata generation unit 282 associates the metadata (such as the array information and the viewpoint number information) with the multiview image encoded data.

[0093] In step S115, the file generation unit 294 generates a multiview image file containing the multiview image encoded data generated in step S114, the meta data, and the depth data generated in step S113. The format of the multiview image file may be of any type. In a case where the multiview image is a still image, for example, the multiview image may be turned into a file in the Exif (Exchangeable image file format) file format. In a case where the multiview image is a moving image, for example, the multiview image may be turned into a file in the MP4 (MPEG-4 Part 14) file format. It is of course possible to use a file format other than the above.

[0094] The file generation unit 294 generates a multiview image file 321 having the structure shown in Fig. 11, for example. In the example shown in Fig. 11, the

multiview image file 321 contains multiview image encoded data 331, depth data 332, and metadata 333.

[0095] The multiview image encoded data 331 is the multiview image encoded data generated in step S114. The depth data 332 is the depth data generated in step S113, and is the depth data of the multiview image of the multiview image encoded data 331. The metadata 333 is the metadata generated in step S102, and is the metadata of the multiview image encoded data 331.

[0096] As shown in Fig. 11, the metadata 333 includes camera module information 341, camera array information 342, viewpoint number information 343, calibration information 344, and base-line length information 345, for example.

[0097] The camera module information 341 is the information related to imaging performed to obtain the multiview image, or is the information about the respective camera modules 242 of the imaging unit 236. In a case where N camera modules 242 are provided in the imaging unit 236, for example, the metadata 333 includes N pieces of camera module information 341. As shown in Fig. 11, the camera module information 341 includes information such as resolution, focal lengths, ISO sensitivity, imaging directions, shutter speeds, F values, and angles of view. The camera module information 341 may of course have any structure. Some of the information may be excluded, or information other than the above may be included.

[0098] The camera array information 342 is the information that indicates the relative positional relationship among the respective camera modules 242. That is, the camera array information 342 is the information that indicates the relative positional relationship among the respective viewpoints of the multiview image. As shown in Fig. 12, the camera array information 342 includes the distances L_x (x = 1 to 8 in the example shown in Fig. 12) from the reference camera module C_0 to the other camera modules C_x (or the distances L_x from the reference viewpoint to the respective viewpoints), and the directions R_x from the reference camera module C_0 toward the other camera modules C_x (or the directions R_x from the reference viewpoint to the respective viewpoints), for example.

[0099] The viewpoint number information 343 is the information that indicates the number of the camera modules 242 (the number of the viewpoints). The calibration information 344 is the information that indicates variations of the respective camera modules 242. The base-line length information 345 is the information that indicates the reference length in the multiview image.

[0100] The metadata 333 may have any structure. Some of the information may be excluded, or information other than the above may be included.

[0101] Fig. 13 is a diagram showing example structures of the respective data in the metadata. As shown in Fig. 13A, the camera module information 341 may include in-

formation such as the resolution, the focal length, the ISO sensitivity, the imaging direction, the shutter speed, the F value, and the angle of view of each of the camera modules 242.

[0102] If those parameters of the respective camera modules 242 have different values from one another, the selection of the captured images to be superimposed on one another, the mixture ratios of the captured images, and are controlled in accordance with the values of the parameters when the respective captured images of the multiview image are superimposed on one another. In this manner, an image with higher quality can be obtained. For example, only captured images having those parameters closer to desired values are superimposed on one another, or captured images having those parameters closer to the desired values are combined at higher rates (the combination ratios of those captured images are made higher), so that an image having those parameters closer to the desired values can be easily obtained. As a result, unnecessary image processing to change the parameters can be reduced. Accordingly, image quality degradation due to the image processing can be reduced (an image with higher quality can be obtained).

[0103] Also, as the respective captured images have various values as the parameters, a captured image having parameters closer to the desired values can be obtained, regardless of the values of the parameters of the image obtained as a result of the superimposition. That is, an image with higher quality can be obtained, regardless of the values of the parameters.

[0104] The camera array information 342 may indicate the array of the camera modules 242 with the relative positional relationship (C_N, L_N, R_N) as in the example shown in Fig. 11, or may indicate a predetermined type of array such as "X type" as in the example shown in Fig. 13A. The degree of freedom of the array can be increased in the example shown in Fig. 11. An increase in the amount of information in the metadata can be reduced in the example shown in Fig. 13.

[0105] The viewpoint number information 343 is shown as a number as in the example shown in Fig. 13A.

[0106] The calibration information 344 may be formed with the information that indicates the positions of the respective viewpoints of the multiview image, for example. In the example shown in Fig. 13A, the calibration information 344 is formed with the coordinate information about the respective camera modules 242 (or the information indicating the central coordinates of the respective camera modules 242). Alternatively, the calibration information 344 may be formed with information that corrects the degrees of luminance of the respective images of the multiview image, for example. In the example shown in Fig. 13B, the calibration information 344 is formed with luminance correction data information about the respective camera modules 242.

[0107] The base-line length information 345 may include the information that indicates the distances from the reference viewpoint to the respective viewpoints of the multiview image, for example. In the example shown in Fig. 13C, the base-line length information 345 includes the information that indicates the distances from the reference camera module 242 to the other camera modules 242.

[0108] Referring back to Fig. 9, in step S116, the data management unit 295 supplies and stores the multiview image file generated in step S115 into the storage unit 263, and generates and manages the file management information 302 about the multiview image file. Also, the user management unit 291 updates the user management information 301 about the user stored in the storage unit 263, and registers the multiview image file associated with the user.

[0109] When the processing in step S116 is finished, the multiview-image using service providing process comes to an end.

[0110] As such a multiview-image using service providing process is performed, a user can more easily register multiview image data obtained by multiview imaging in the server 202. Also, the multiview image data and the data related to the multiview image (such as depth data and metadata) are turned into a file and are then managed. Accordingly, the user can more easily use the multiview image data he/she has registered. That is, the multiview-image using service providing system 200 (the multiview-image using service platform 100) can increase the user-friendliness of the multiview-image using service.

[0111] In the above description, multiview imaging is performed by using the imaging unit 236 including the camera modules 242, to generate a multiview image (multiview image data). However, a multiview image (multiview image data) may be generated by any method. For example, a multiview image may be generated by performing imaging (capturing a moving image or capturing still images) while moving the imaging position and the imaging direction (or the viewpoint) by using an imaging unit including a single imaging element and an optical system (or an imaging unit including a single camera module 242). In that case, the information about the changes in the imaging position and the imaging direction (or the viewpoint) is preferably associated as metadata with multiview image data (multiview image encoded data).

[0112] Also, in the above description, the multiview image file generated by the file generation unit 294 is stored and managed in the storage unit 263 of the server 202. However, a multiview image file may be managed in any other site. For example, a multiview image file may be stored and managed in a device other than the server 202 (such as a file management server (not shown)). In that case, the file generation unit 294 transmits the generated multiview image file as a bit stream or auxiliary information about a bit stream to the device via the communication unit 264, for

example. In that case, the device includes a communication unit that acquires the multiview image file by communicating with the server 202, a storage unit that stores the acquired multiview image file, and a data management unit as the functional block that manages the multiview image file stored in the storage unit, updates the multiview image file or supplies the multiview image file to another device such as the terminal device 201 or the server 202 where necessary.

[0113] Further, in the above description, a multiview image file is generated in the server 202. However, a multiview image file may be generated in any device. For example, a multiview image file may be generated in the terminal device 201. In that case, the CPU 221 of the terminal device 201 further includes the necessary functional block such as the file generation unit 294 as appropriate. In such a case, the file generation unit 294 generates a multiview image file after multiview image data is encoded by the encoding unit 283 (or after the processing in step S103). In step S104, the transmission control unit 284 transmits the multiview image file as a bit stream or auxiliary information about a bit stream to the server 202, for example. In step S111, the acquisition control unit 292 controls the communication unit 264, to acquire the multiview image file.

[0114] <Flow of the Depth Detection Process>

Referring now to the flowchart in Fig. 14, an example flow of the depth detection process to be performed in step S113 in Fig. 9 is described.

[0115] When the depth detection process is started, the depth detection unit 293 acquires the metadata 333 in step S131. In step S132, the depth detection unit 293 corrects the resolution of each of the captured images in accordance with the resolution and the like of each of the camera modules 242.

[0116] In step S133, the depth detection unit 293 corrects the luminance of each of the captured images in accordance with the shutter speed and the like of each of the camera modules 242. In step S134, the depth detection unit 293 sets the area to be used in the depth calculation in accordance with the angle of view of each of the camera modules 242.

[0117] In step S135, the depth detection unit 293 corrects the shift length at the time of disparity evaluation based on the base-line length information 345 and the like. In step S136, the depth detection unit 293 determines the reference camera, the matching axis, the image interpolation method, and the like based on the camera array, the number of viewpoints, and the like.

[0118] In step S137, the depth detection unit 293 corrects each of the captured images based on the calibration information 344. In step S138, the depth detection unit 293 estimates the depth by repeating stereo matching or the like, and detects depth data.

[0119] After the depth data is detected, the process returns to the process shown in Fig. 9.

[0120] As the depth detection process is performed in the above described manner, a user can generate and use depth data more easily.

[0121] <3. Third Embodiment>

<Application Sales>

As described above in the first embodiment, the multiview-image using service platform 100 can provide a service to sell the application 112 through the application market 102, for example. In this embodiment, the sales of the application are described.

[0122] <Multiview-Image Using Service Providing System>

Fig. 15 is a diagram showing a typical example structure of a multiview-image using service providing system. The multiview-image using service providing system 200 shown in Fig. 15 is an example of a system to which the present technique is applied. In this system, a server 202 provides a multiview-image using service to a terminal device 401 connected thereto via a network 210. That is, the multiview-image using service providing system 200 is an example of a structure that realizes the multiview-image using service platform 100.

[0123] Fig. 15 shows an example of a structure related to the provision of a service related to sales or provision of the application 112 among the services to be provided by the multiview-image using service platform 100. In Fig. 15, the multiview-image using service providing system 200 includes the terminal device 401, the server 202, and an application providing server 402 that are connected to the network 210.

[0124] The terminal device 401 connected to the network 210 in a wired or wireless manner communicates with the server 202, to carry out the procedure to purchase the application 112. The terminal device 401 may be the same as the terminal device 201, or may differ from the terminal device 201. The terminal device 401 basically has the same structure as the terminal device 201. Therefore, the structure illustrated in Fig. 4 can also be applied to the terminal device 401. In the case of the terminal device 401, however, the functions related to imaging are unnecessary. Therefore, the imaging unit 236 can be omitted.

[0125] The application providing server 402 is the server that provides the application 112 to the multiview-image using service platform 100 (the application market 102). The server 202 sells or provides the application provided by the application providing server 402 to (the user of) the terminal device 401.

[0126] <Server>

Fig. 16 is a block diagram showing a typical example structure of the application providing server 402. As shown in Fig. 16, in the application providing server 402, a CPU 411, a ROM 412, and a RAM 413 are connected to one another via a bus 414.

[0127] An input/output interface 420 is also connected to the bus 414. An input unit 421, an

output unit 422, a storage unit 423, a communication unit 424, and a drive 425 are connected to the input/output interface 420.

[0128] The input unit 421 is formed with an input device that receives external information such as a user input. The input unit 421 includes operation buttons, a touch panel, a microphone, a camera, and an input terminal, for example. The input unit 421 may also include various kinds of sensors, such as an acceleration sensor, an optical sensor, and a temperature sensor. The output unit 422 is formed with an output device that outputs information such as images and sound. The output unit 422 includes a display, a speaker, and an output terminal, for example.

[0129] The storage unit 423 is formed with a hard disk, a RAM disk, a nonvolatile memory, or the like. The communication unit 424 is formed with a network interface, for example. The drive 425 drives a removable medium 431 such as a magnetic disk, an optical disk, a magnetooptical disk, or a semiconductor memory.

[0130] The CPU 411 performs various kinds of processes by loading a program stored in the storage unit 423 into the RAM 413 via the input/output interface 420 and the bus 414, and executing the program. Necessary data for the CPU 411 to perform various kinds of processes and the like are also stored in the RAM 413 as appropriate.

[0131] The program to be executed by the CPU 411 can be recorded on the removable medium 431 as a packaged medium, for example, and be provided to the application providing server 402. In this case, the program can be installed into the storage unit 423 via the input/output interface 420 when the removable medium 431 is mounted in the drive 425.

[0132] Alternatively, the program can be provided to the application providing server 402 via a wired or wireless transmission medium such as a LAN, the Internet, or digital satellite broadcasting. In this case, the program can also be received by the communication unit 424 via a wired or wireless transmission medium, and be installed into the storage unit 423.

[0133] Also, the program can be installed in the ROM 412 or the storage unit 423 in advance.

[0134] <Functional Blocks>

The terminal device 401 has a function shown as a functional block in Fig. 17A, as the CPU 221 executes a predetermined program. As shown in Fig. 17A, the CPU 221 has a functional block such as an application purchase processing unit 441.

[0135] The application purchase processing unit 441 controls respective components such as the input unit 231, the output unit 232, the storage unit 233, and the communication unit 234, communicates with the server 202, and performs a process related to application purchases by displaying images and receiving user instructions.

[0136] Meanwhile, the server 202 has functions shown as functional blocks in Fig. 17B, as

the CPU 251 executes a predetermined program. As shown in Fig. 17B, the CPU 251 has functional blocks such as a user management unit 451, an application sales processing unit 452, and a data management unit 453.

[0137] Like the user management unit 291, the user management unit 451 performs a process related to management of users to whom multiview-image using services are to be provided. The application sales processing unit 452 controls the communication unit 264 to communicate with the terminal device 401 or the like, and performs a process related to application sales. Like the data management unit 295, the data management unit 453 performs a process related to management of data such as a multiview image file. The data management unit 453 also performs a process related to management of the application supplied from the application providing server 402.

[0138] Further, the application providing server 402 has a function shown as a functional block in Fig. 17C, as the CPU 411 executes a predetermined program. As shown in Fig. 17C, the CPU 411 has a functional block such as an application provision processing unit 461.

[0139] The application provision processing unit 461 controls the communication unit 424 to communicate with the server 202 or the like, and performs a process related to the provision of the application to the server 202.

[0140] <Flow of a Multiview-Image Using Service Providing Process>

The terminal device 401, the server 202, and the application providing server 402 of the multiview-image using service providing system having the above described structure perform a multiview-image using service providing process to provide a service using multiview images, or provide a service such as application sales in this embodiment. Referring now to the flowchart shown in Fig. 18, an example flow of the multiview-image using service providing process to be performed by those devices is described.

[0141] In step S171, the application provision processing unit 461 of the application providing server 402 controls the communication unit 424, to supply the application to be provided to the server 202 and register the application therein.

[0142] In step S161, the data management unit 453 of the server 202 controls the communication unit 264 or the like to acquire the application supplied from the application providing server 402, stores the application into the storage unit 263, and manages the application so that the application can be sold to the terminal device 401.

[0143] In step S151, the application purchase processing unit 441 of the terminal device 401 controls the communication unit 234, to request an application purchase from the server 202.

[0144] In step S162, the application sales processing unit 452 of the server 202 controls the communication unit 264 or the like, to acquire the request.

[0145] In step S163, the application sales processing unit 452 cooperates with the user management unit 451 and the data management unit 453, to create a list of applications that can be sold to the user. The application sales processing unit 452 then controls the communication unit 264 or the like, to provide the application list to the terminal device 401.

[0146] In step S152, the application purchase processing unit 441 of the terminal device 401 acquires the application list. The application purchase processing unit 441 controls the output unit 232 or the like, to display the application list on a monitor or the like, so that the application list is presented to the user, and an instruction is received from the user.

[0147] For example, the GUI (Graphical User Interface) 471 shown in Fig. 19A is displayed on the monitor of the terminal device 401. Based on such a GUI, the user selects a desired application from a number of applications. In a case where an application for lens simulations is selected, for example, the GUI 472 shown in Fig. 19B is displayed, and a virtual lens is selected. In a case where an application for editing images is selected, for example, the GUI 473 shown in Fig. 19C is displayed, and an editing function such as a decorating stamp is selected.

[0148] Referring back to Fig. 18, when the user selects the application to be purchased from the list, the application purchase processing unit 441 in step S153 receives the selection instruction, and controls the communication unit 234 or the like, to supply control information for selecting the application to be purchased to the server 202.

[0149] In step S164, the application sales processing unit 452 of the server 202 controls the communication unit 264 or the like, to acquire the control information. In step S165, the application sales processing unit 452 cooperates with the user management unit 451 and the data management unit 453, and associates the user management information 301 about the user with the selected application (the application designated by the user in the instruction to purchase), so that the selected application is registered with the user.

[0150] In step S166, the application sales processing unit 452 performs a payment process related to the sale of the application. The user management unit 451 causes the user management information 301 about the user to reflect the payment information. (The points equivalent to the price or fee are subtracted from the points or money owned by the user, for example. This sale is added to the past purchases of the application.)

[0151] When the processing in step S166 is finished, the multiview-image using service providing process comes to an end.

[0152] As such a multiview-image using service providing process is performed, a user can more easily purchase an application by performing a process using multiview images. Also, as the purchased applications are registered with the user and are managed in the

server 202, the user can more easily use the applications he/she has purchased. That is, the multiview-image using service providing system 200 (the multiview-image using service platform 100) can increase the user-friendliness of the multiview-image using service.

[0153] Applications may not be sold, and may be provided for free. In that case, the payment process can be skipped.

[0154] <4. Fourth Embodiment>

<Virtual Lens Processing>

By performing an application provided to a user as described above, the multiview-image using service platform 100 can provide various services using multiview images to the user.

[0155] In this embodiment, execution of an application for performing the lens simulation (virtual lens processing) described in the first embodiment is described as an example of the application.

[0156] <Multiview-Image Using Service Providing System>

Fig. 20 is a diagram showing a typical example structure of a multiview-image using service providing system. The multiview-image using service providing system 200 shown in Fig. 20 is an example of a system to which the present technique is applied. In this system, a server 202 provides a multiview-image using service to a terminal device 401 connected thereto via a network 210. That is, the multiview-image using service providing system 200 is an example of a structure that realizes the multiview-image using service platform 100.

[0157] Fig. 20 shows an example of a structure related to the provision of a service related to a lens simulation (virtual lens processing) among the services to be provided by the multiview-image using service platform 100. In Fig. 20, the multiview-image using service providing system 200 includes the terminal device 401 and the server 202 that are connected to the network 210.

[0158] The terminal device 401 connected to the network 210 in a wired or wireless manner communicates with the server 202, to select the multiview image to be used in the lens simulation, select the virtual lens to be simulated, and set user designated parameters that are imaging-related parameters having values designated by a user, such as a focusing position and a depth of field.

[0159] Based on those processes, the server 202 performs virtual lens processing to simulate a virtual lens, and generates virtual captured image data obtained by imaging with the use of the virtual lens. The server 202 also saves (stores, and manages) the virtual captured image data. Further, the server 202 generates and saves (stores, and manages) history information as application parameters of the application for performing the lens simulation. The history information indicates what value has been set for which

parameter, what kind of operation (instruction) has been performed by the user, what kind of processing has been performed, and the like.

[0160] <Outline of the Virtual Lens Processing>

Next, an outline of virtual lens processing is described. In the virtual lens processing, a virtual lens 150 designated by a user as shown in Fig. 2A is set, and a ray vector 151 that is light incident on the virtual lens 150 from a subject, a ray vector 152 that is the incident light after passing through the virtual lens 150, a virtual image sensor 153 that obtains a virtual captured image from the ray vector 152, and the like are simulated, and a virtual captured image is generated from a multiview image based on the simulations.

[0161] For example, the interpolating images 502 and the depth data 503 shown in Fig. 21B are generated from the multiview image 501 shown in Fig. 21A, for example, and a virtual captured image 504 obtained by imaging with the use of the virtual lens 150 (the virtual optical system shown in Fig. 2A) as shown in Fig. 21C is generated by using the interpolating images 502 and the depth data 503.

[0162] In the above manner, the virtual captured image 504 that is larger than the respective captured images of the multiview image 501, and reflects the optical effects given by the virtual lens 150 is obtained. An optical system such as the virtual lens 150 is simulated by using profile information unique to the virtual optical system. The profile information is formed with parameters for reproducing the optical effects of the virtual optical system. Therefore, the server 202 can readily reproduce various optical systems that range from existing ones to unrealistic ones. In short, a user can obtain various kinds of captured images at low costs through this service. That is, the multiview-image using service providing system 200 (the multiview-image using service platform 100) can increase the user-friendliness of the multiview-image using service.

[0163] <Functional Blocks>

The terminal device 401 has functions shown as functional blocks in Fig. 22A, as the CPU 221 executes a predetermined program. As shown in Fig. 22A, the CPU 221 has functional blocks such as a user instruction reception processing unit 511, a display control unit 512, and a transmission control unit 513.

[0164] The user instruction reception processing unit 511 controls the input unit 231 or the like, to perform a process related to reception of a user instruction. The display control unit 512 controls the output unit 232 or the like, to perform a process related to display control to display an image such as a GUI or a guide on a monitor. The transmission control unit 513 controls the communication unit 234 or the like, to perform a process related to transmission of various kinds of information such as a user instruction received by the user instruction reception processing unit 511.

[0165] Meanwhile, the server 202 has functions shown as functional blocks in Fig. 22B, as

the CPU 251 executes a predetermined program. As shown in Fig. 22B, the CPU 251 has functional blocks such as a user management unit 521, an application selection processing unit 522, an image selection processing unit 523, a lens selection processing unit 524, a user designated parameter setting unit 525, a virtual lens processing unit 526, and a data management unit 527.

[0166] Like the user management unit 291, the user management unit 521 performs a process related to management of users to whom multiview-image using services are to be provided. The application selection processing unit 522 controls the communication unit 264 to communicate with the terminal device 401 or the like, and performs a process related to selection of the application to be executed. The image selection processing unit 523 controls the communication unit 264 to communicate with the terminal device 401 or the like, and performs a process related to selection of a multiview image to be the current multiview image in the lens simulation (virtual lens processing). The lens selection processing unit 524 controls the communication unit 264 to communicate with the terminal device 401 or the like, and performs a process related to selection of profile information about the virtual lens to be simulated. The user designated parameter setting unit 525 controls the communication unit 264 to communicate with the terminal device 401 or the like, and performs a process related to the setting of user designated parameters transmitted from the terminal device 401. The virtual lens processing unit 526 performs a process related to the simulation of a virtual optical system. Like the data management unit 295, the data management unit 527 performs a process related to management of data such as a multiview image file, and management of an application and data related to the application.

[0167] <Flow of a Multiview-Image Using Service Providing Process>

The terminal device 401 and the server 202 of the multiview-image using service providing system having the above described structure perform a multiview-image using service providing process to provide a service using multiview images, or provide a service such as a lens simulation in this embodiment. Referring now to the flowchart shown in Fig. 23, an example flow of the multiview-image using service providing process to be performed by those devices is described.

[0168] In step S201, the user instruction reception processing unit 511 of the terminal device 401 controls the input unit 231 or the like, to receive an instruction to request startup of an application from a user. The transmission control unit 513 controls the communication unit 234 or the like, to supply the application startup request received by the user instruction reception processing unit 511 to the server 202.

[0169] In step S221, the application selection processing unit 522 of the server 202 controls the communication unit 264 or the like, to acquire the request. In step S222, the application selection processing unit 522, in response to the request, generates a list of

applications that can be used by the user based on the user management information being managed by the user management unit 521, and controls the communication unit 264 or the like, to supply the list to the terminal device 401.

[0170] In step S202, the transmission control unit 513 of the terminal device 401 controls the communication unit 234 or the like, to acquire the list. The display control unit 512 controls the output unit 232, to display the acquired list as an image on a monitor. The user then selects the application to be started from the list.

[0171] In step S203, the user instruction reception processing unit 511 controls the input unit 231 or the like, to receive an instruction as to the selection of the application to be started from the user. The transmission control unit 513 controls the communication unit 234 or the like, to supply the application-to-start selection instruction received by the user instruction reception processing unit 511 to the server 202.

[0172] In step S223, the application selection processing unit 522 of the server 202 controls the communication unit 264 or the like, to acquire the selection instruction. In step S224, the image selection processing unit 523 generates a list of multiview images of the user based on the user management information being managed by the user management unit 521, and controls the communication unit 264 or the like, to supply the list to the terminal device 401.

[0173] In step S204, the transmission control unit 513 of the terminal device 401 controls the communication unit 234 or the like, to acquire the list. The display control unit 512 controls the output unit 232, to display the acquired list as an image on the monitor. The user then selects the multiview image to be the current multiview image from the list.

[0174] In step S205, the user instruction reception processing unit 511 controls the input unit 231 or the like, to receive an instruction as to the selection of the current image from the user. The transmission control unit 513 controls the communication unit 234 or the like, to supply the current image selection instruction received by the user instruction reception processing unit 511 to the server 202.

[0175] In step S225, the image selection processing unit 523 of the server 202 controls the communication unit 264 or the like, to acquire the selection instruction. In step S226, the lens selection processing unit 524 generates a list of the lenses registered with the user based on the user management information being managed by the user management unit 521, and controls the communication unit 264 or the like, to supply the list to the terminal device 401.

[0176] In step S206, the transmission control unit 513 of the terminal device 401 controls the communication unit 234 or the like, to acquire the list. The display control unit 512 controls the output unit 232, to display the acquired list as an image on the monitor. The user then selects the virtual lens to be simulated from the list.

[0177] In step S207, the user instruction reception processing unit 511 controls the input unit 231 or the like, to receive a lens selection instruction from the user. The transmission control unit 513 controls the communication unit 234 or the like, to supply the lens selection instruction received by the user instruction reception processing unit 511 to the server 202.

[0178] In step S227, the lens selection processing unit 524 of the server 202 controls the communication unit 264 or the like, to acquire the selection instruction.

[0179] In step S208, the user instruction reception processing unit 511 of the terminal device 401 controls the input unit 231 or the like, to receive user designated parameters that are imaging-related parameters such as imaging conditions having values designated by the user. The transmission control unit 513 controls the communication unit 234 or the like, to supply the user designated parameters received by the user instruction reception processing unit 511 to the server 202.

[0180] In step S228, the user designated parameter setting unit 525 of the server 202 controls the communication unit 264 or the like, to acquire the user designated parameters.

[0181] In step S229, the virtual lens processing unit 526 performs virtual lens processing to generate a virtual captured image that is obtained by capturing an image of the subject in the multiview image selected in step S225 with the virtual lens selected in step S227 while using the multiview image data and the profile information including the parameters for reproducing the optical effects of a virtual optical system. In doing so, the virtual lens processing unit 526 reproduces the optical influence of the virtual lens with higher precision by using the user designated parameters acquired in step S228. Also, in doing so, the virtual lens processing unit 526 generates interpolating images for the multiview image in accordance with the camera array information 342, the viewpoint number information 343, and the depth data 332 included in the multiview image file of the multiview image selected in step S225. The virtual lens processing will be described later in detail.

[0182] In step S230, the virtual lens processing unit 526 controls the communication unit 264 or the like, to supply the data of the virtual captured image generated by the processing in step S229 to the terminal device 401.

[0183] In step S209, the transmission control unit 513 of the terminal device 401 acquires the data of the virtual captured image. The display control unit 512 controls the output unit 232, to display the acquired virtual captured image on the monitor. Based on the virtual captured image, the user determines whether to save the virtual captured image.

[0184] In step S210, the user instruction reception processing unit 511 controls the input unit 231 or the like, to receive an instruction to save the data of the virtual captured image from the user. The transmission control unit 513 controls the communication unit 234

or the like, to supply the virtual captured image data saving instruction received by the user instruction reception processing unit 511 to the server 202.

[0185] In step S231, the data management unit 527 of the server 202 controls the communication unit 264 or the like, to acquire the virtual image data saving instruction. In step S232, the data management unit 527 generates application parameters about this lens simulation. The data management unit 527 stores and manages the data and the application parameters of the virtual captured image generated by the processing in step S229, and also registers the data and the application parameters with the user (or updates the user management information about the user).

[0186] When the processing in step S232 is finished, the multiview-image using service providing process comes to an end.

[0187] As such a multiview-image using service providing process is performed, a user can perform a virtual lens simulation more easily by using a multiview image (or generate a virtual captured image obtained by imaging with the use of a virtual lens). Also, as the generated virtual captured image data is registered with the user and is managed in the server 202, the user can use the virtual captured image data more readily. Furthermore, as the virtual captured image data is managed in association with the multiview image, the application parameters, and the like used in generating the virtual captured image, the user can more readily use the virtual captured image data as well as the other related data. That is, the multiview-image using service providing system 200 (the multiview-image using service platform 100) can increase the user-friendliness of the multiview-image using service.

[0188] <Example of a Screen>

Fig. 24 is a schematic view of an example of a setting GUI displayed on the display unit 531.

[0189] The screen shown in Fig. 24 displays a setting GUI as well as a preview image Pv. In the example shown in Fig. 24, development parameters are formed with the design information about the lens, the shape of the aperture, and the focus position.

[0190] In this case, a lens unit selection portion DL, an aperture shape selection portion DA, and a focus position selection portion DF are superimposed on the preview image Pv, and are displayed as the setting GUI on the display unit 531.

[0191] The lens unit selection portion DL displays figures that represent lens units based on selection candidates for the design information about a lens in the development parameters. The aperture shape selection portion DA displays figures that represent selection candidates for the aperture shape in the development parameters. The focus position selection portion DF displays a setting bar Fb that indicates the position of a selection candidate for the focus position.

[0192] The user touches, with a finger U, the figure that represents a desired lens unit

displayed in the lens unit selection portion DL, to select a selection candidate for the design information about the lens corresponding to the lens unit. The user also touches, with the finger U, the figure that represents a desired aperture shape displayed in the aperture shape selection portion DA, to select a selection candidate for the aperture shape.

[0193] The user also touches, with the finger U, the setting bar Fb in the focus position selection portion DF, and moves the finger U up and down, to move the setting bar Fb to the position corresponding to a desired focus position. In this manner, the user can select a selection candidate in a desired focus position.

[0194] The setting bar Fb may not be moved by the user moving the finger U after touching the setting bar Fb with the finger U. Instead, the setting bar Fb may be moved to a desired position in the focus position selection portion DF by the user touching the desired position. Also, a selection candidate for the focus position may not be displayed. Instead, the selection candidate for the focus position closest to the subject in the position touched with the finger U in the screen may be selected.

[0195] In the example shown in Fig. 24, the lens unit selection portion DL is located in the upper left corner of the preview image Pv, the aperture shape selection portion DA is located in the lower left corner, and the focus position selection portion DF is located on the right side. However, the positions of the respective portions are not limited to the above.

[0196] Although not shown in the drawing, selection candidates for other development parameters related to white balance, exposure correction, and the like may be displayed as well as the lens unit selection portion DL, the aperture shape selection portion DA, the focus position selection portion DF, and the like.

[0197] In the second embodiment, the display unit 531 is formed integrally with a touch panel. In a case where the display unit 531 is not formed integrally with a touch panel, however, a user moves a pointer displayed in the screen by operating a mouse or the like (not shown), to perform a selecting operation that is equivalent to a touch panel operation.

[0198] <Flow of the Virtual Lens Processing>

Referring now to the flowchart shown in Fig. 25, an example flow of the virtual lens processing performed in step S229 in Fig. 23 is described in detail.

[0199] When the virtual lens processing is started, the virtual lens processing unit 526 in step S251 acquires the selected multiview image file from the storage unit 263. In step S252, the virtual lens processing unit 526 acquires the profile information about the selected lens from the storage unit 263.

[0200] The site where multiview image files and profile information are stored and managed is not fixed, and may not be the storage unit 263. For example, multiview image files

and profile information may be stored and managed in a device other than the server 202, such as the terminal device 401. In that case, the virtual lens processing unit 526 controls the communication unit 264, for example, to acquire a multiview image file and profile information from the device in which the file and the information are stored. The site where multiview image files are stored and the site where profile information is stored may differ from each other.

[0201] Profile information is formed with parameters for reproducing the optical effects of a virtual optical system, and is unique to the virtual optical system. The profile information includes the PSF (Point Spread Function) data of the respective colors of RGB, an aperture shape, interpolation number designation information, and the like.

[0202] The PSF data is also referred to as a point spread function or a point-image distribution function, and is the function that indicates responses of the virtual lens included in the virtual optical system to a point light source. In other words, the PSF data is the data that indicates the influence of a virtual lens on light rays of RGB passing through the virtual lens. Fig. 26A shows an example of the PSF data. In this example, the PSF data in accordance with distances to the focusing point (or the point light source) are shown for the respective colors (in the respective rows).

[0203] The aperture shape is the information that indicates the shape of the virtual aperture included in the virtual optical system. This aperture shape may be an actually existing aperture shape, or may be an unrealistic shape such as a round shape, the shape of a star, or the shape of an X shown in the left portion of Fig. 26B. The aperture shape can be designated by any method. For example, a predetermined shape may be designated by identification information (ID) or the like. The aperture shape may be expressed by an intensity distribution 542 as shown in the right portion of Fig. 26B, for example. The size of the intensity distribution (the number of intensities) depends on the number of interpolating images (the interpolation number) designated by the interpolation number designation information. Where the interpolation number is N, for example, the aperture shape is expressed by the N x N intensity distribution 542.

[0204] The interpolation number designation information is the information that designates the number of interpolating images to be generated when a virtual captured image is generated. That is, in the virtual lens processing, the virtual lens processing unit 526 generates the number of interpolating images as designated by the interpolation number designation information. Where the number of interpolating images is larger, a virtual captured image with higher definition can be obtained. Normally, where the virtual lens has a higher grade (higher performance), the number of interpolating images is larger.

[0205] As described above, the lens profile information is formed with the information that indicates the features of the virtual lens. The contents of the lens profile information

are not fixed. Some of the above described information may be excluded, or information other than the above described information may be included. For example, the physical design information about the lens to be used for emulating the virtual lens may be included in the lens profile information.

[0206] Referring back to Fig. 25, in step S253, the virtual lens processing unit 526 sets the user designated parameters acquired in step S228 in Fig. 23.

[0207] The user designated parameters are imaging-related parameters that have values designated by the user. In accordance with the user designated parameters, the virtual lens processing unit 526 generates a virtual captured image. For example, the user designated parameters include focusing position designation information, a depth-of-field designation information, super-resolution processing instruction information, and the like.

[0208] The focusing position designation information (focus position designation information) is the information that designates an area (or a point) where the subject on which the focus is to be put is located in the captured image. When the user designates a position in the captured image as the focusing position, a virtual captured image is generated so that the focal point is on the subject located in the focusing position.

[0209] The depth-of-field designation information is the information that designates a depth of field (an aperture size). The super-resolution processing instruction information is the information that includes instructions related to super-resolution processing, such as an instruction as to whether super-resolution processing is to be performed when the respective captured images of the multiview image are superimposed on one another to generate a virtual captured image, and an instruction as to in which area and to what extent the super-resolution processing is to be performed if it is determined to be performed. The super-resolution processing at the time of the superimposition of the respective captured images of the multiview image is performed based on the super-resolution processing instruction information.

[0210] The contents of the user designated parameters are of course not fixed. Some of the above described information may be excluded, or information other than the above described information may be included.

[0211] In step S254, the virtual lens processing unit 526 determines the reference camera, the matching axis, the image interpolation method, and the like based on the camera array information, the viewpoint number information, and the like included in the metadata associated with the current multiview image data.

[0212] In step S255, the virtual lens processing unit 526 determines the combination ratios of the respective images to be used in image interpolation (or the respective images to be superimposed) in accordance with the positions of the interpolating images to be generated.

[0213] In step S256, the virtual lens processing unit 526 generates interpolating images in accordance with the depth data and the various kinds of parameters that are set in the above described manner. For example, the virtual lens processing unit 526 generates interpolating image by superimposing an image of the reference viewpoint determined in step S254 and the images designated by the interpolation method determined in step S254 by using the matching axis determined in step S254, in accordance with the depth data. The virtual lens processing unit 526 generates the number of interpolating images as designated by the interpolation number designation information in the profile information.

[0214] In step S257, the virtual lens processing unit 526 causes each of the interpolating images to reflect the aperture shape data in the profile information.

[0215] In step S258, based on the depth data, the virtual lens processing unit 526 calculates the depth value of the focusing position (the focus position) designated by the user. Specifically, in the virtual captured image to be generated, the virtual lens processing unit 526 calculates the depth value of the subject (the distance to the subject) located in the position (coordinates) designated by the focusing position designation information (the focus position designation information) included in the user designated parameters acquired in step S228, for example.

[0216] In step S259, the virtual lens processing unit 526 sets the depth of field designated by the depth-of-field designation information in the user designated parameters.

[0217] In step S260, the virtual lens processing unit 526 generates a virtual captured image by superimposing the multiview image and the interpolating images by repeating stereo matching or the like. In doing so, the virtual lens processing unit 526 reflects the PSF data of the virtual lens in accordance with the depth data (the depth value of the subject). Also, the virtual lens processing unit 526 generates the virtual captured image so that the focus is achieved at the depth value (distance) calculated in step S258. Furthermore, the virtual lens processing unit 526 causes each of the interpolating images to reflect the aperture shape data in step S257, so that the virtual captured image can reflect the virtual aperture shape. Also, the virtual lens processing unit 526 generates the virtual captured image so that the depth of field set in step S259 is achieved.

[0218] In step S261, the virtual lens processing unit 526 performs super-resolution processing on the virtual captured image in accordance with the super-resolution processing instruction information in the user designated parameters. In a case where the super-resolution processing instruction information instructs not to perform the super-resolution processing, for example, the virtual lens processing unit 526 does not perform the super-resolution processing. In a case where the super-resolution processing instruction information instructs to perform the super-resolution processing, for example, the virtual lens processing unit 526 performs the super-resolution

processing.

[0219] The super-resolution processing may be performed on the entire virtual captured image, or may be performed only on the predetermined area that has the depth value of the focusing position. Even if the super-resolution processing is performed on the area of the subject on which any focus is put, the effect to be achieved (an increase in image quality) is small. Therefore, the super-resolution processing is performed only on the area that has a depth value equal or similar to the depth value of the focusing position, so that the processing load can be reduced while image quality degradation is suppressed. The area where the super-resolution processing is to be performed may also be designated by the super-resolution processing instruction information.

[0220] When the processing in step S261 is finished, the virtual lens processing comes to an end, and returns to the process shown in Fig. 23.

[0221] As the virtual lens processing is performed in the above described manner, a user can obtain a virtual captured image more readily.

[0222] The virtual lens processing described above may not be performed by the server 202, but may be performed by some other device. For example, the CPU 221 of the terminal device 401 may have the virtual lens processing unit 526 or the like to perform the virtual lens processing in the terminal device 401. In that case, the virtual lens processing can be performed basically in the same manner as in the above described example. The information that is to be used in the virtual lens processing and is stored (managed) in the server 202, such as a multiview image file and the profile information about a virtual lens, may be transmitted to the terminal device 401 where necessary.

[0223] <5. Fifth Embodiment>

<Sales Support>

In this embodiment, execution of an application for performing the sales support described in the first embodiment is described as another example of the application. In this embodiment, an application for supporting sales of furniture as described in the first embodiment is described as an example of the sales support.

[0224] <Multiview-Image Using Service Providing System>

Fig. 27 is a diagram showing a typical example structure of a multiview-image using service providing system. The multiview-image using service providing system 200 shown in Fig. 27 is an example of a system to which the present technique is applied. In this system, a server 202 provides a multiview-image using service to a terminal device 201 connected thereto via a network 210. That is, the multiview-image using service providing system 200 is an example of a structure that realizes the multiview-image using service platform 100.

[0225] Fig. 27 shows an example of a structure related to the provision of a service related to the sales support (furniture sales support) among the services to be provided by the

multiview-image using service platform 100. In Fig. 27, the multiview-image using service providing system 200 includes the terminal device 201, the server 202, and a furniture sales server 601 that are connected to the network 210.

[0226] The terminal device 201 captures images of a subject to perform multiview imaging and obtain a multiview image. The terminal device 201 also detects the depth of the multiview image obtained through the multiview imaging. Furthermore, the terminal device 201 generates a virtual captured image by using the multiview imaging. The terminal device 201 also performs a process related to the placement of a furniture image in the virtual captured image. The terminal device 201 further turns the multiview image data and the like into a file, to generate a multiview image file.

[0227] The terminal device 201 and the server 202 that are connected to the network 210 in a wired or wireless manner communicate with each other, to perform processes such as selection of furniture data, transmission of three-dimensional modeling data (3D modeling data), furniture purchase procedures, and transmission of various kinds of data.

[0228] The server 202 performs processes such as saving of various kinds of data supplied from the terminal device 201.

[0229] The server 202 and the furniture sales server 601 that are connected to the network 210 in a wired or wireless manner communicate with each other, to perform processes such as provision of three-dimensional modeling data (3D modeling data) and furniture purchase procedures.

[0230] The furniture sales server 601 is the server that performs processes related to sales of furniture or sales support. Specifically, the furniture sales server 601 processes payment in sales of furniture, and provides the furniture image and the 3D modeling data thereof to be used in the sales support, and the like, as described above. The furniture sales server 601 has basically the same structure as the application providing server 402. Therefore, the structure illustrated in Fig. 15 can also be applied to the furniture sales server 601.

[0231] <Furniture Sales Support>

Next, a sales support method in a furniture sales support service to be provided by the above described multiview-image using service providing system 200 is described in detail. A product support service to be provided by the multiview-image using service platform 100 to which the present technique is applied is a service that virtually places an object as an image of the product being currently promoted in a desired background image, to cause a user to envision a situation where the product is actually used. The furniture sales support service to be provided by the multiview-image using service providing system 200 shown in Fig. 27 uses an image of the furniture being currently promoted (furniture image) as an example of the object, and uses a virtual

captured image as an example of the background image. That is, this furniture sales support service is a service that places a furniture image in a virtual captured image, to cause a user to envision a situation where the furniture is actually placed in a room or the like. In doing so, the furniture sales support service not only combines the virtual captured image with the furniture image, but also sets the size and the orientation of the furniture image in accordance with the placement position of the furniture image by using the depth data of the virtual captured image. Accordingly, it is possible to cause the user to envision a more accurate situation.

[0232] More specifically, the terminal device 201 generates the virtual captured image 611 shown in Fig. 28A from a multiview image obtained by multiview imaging. For example, the user performs multiview imaging on the room to be furnished with the furniture to be purchased, and generates the virtual captured image 611 of the room. The terminal device 201 also generates the depth data (depth map) 612 of the virtual captured image 611 as shown in Fig. 28B from the multiview image obtained by the multiview imaging.

[0233] The terminal device 201 then acquires the image (the furniture image) of the furniture being sold by the furniture sales server 601 and the 3D modeling data thereof from the server 202, and places the furniture image in the virtual captured image 611 (the room image) as in the combined image 613 shown in Fig. 28C. Here, the 3D modeling data may be a data to display three dimensional shape of the object such as furniture. The 3D modeling data can be information related with coordinates which indicate height, width, and depth of each position organizing external shape of the object, or the 3D modeling data can be set of polygons to organize external surfaces of the object, or set of free form curve lines based on the coordinates, and the like. Or more specifically, 3D modeling data could be information just indicating height, width, and depth of whole object. Further, 3D modeling data could include information defining color, texture, design pattern, reflectance or transparence of each surface organizing the external shape of the object. The placing of the furniture image is performed by using the depth data 612, and the size and the orientation of the furniture image are appropriately set in accordance with the distance to the placement position of the furniture image in the depth direction and the like. Specifically, for example, the terminal device 201 determines a modeling condition at the placement position in the virtual captured image 611 based on the acquired 3D modeling data. Here, the modeling condition may be a condition of the 3D modeling data applied the size and the orientation based on the placement position when the 3D modeling data is placed. Further, for example, the terminal device can also determine the modeling condition as a change of the color or the texture associated with light source and the placement position, or a change of a shape if the object could be changed in shape in response to

the placement position.

[0234] Also, the depth-direction positional relationship (the degree of overlapping) with other subjects in the image can be accurately reproduced in accordance with the distance to the placement position in the depth direction, as in the image shown in Fig. 29B, which shows a Christmas tree placed behind the person shown in the image in Fig. 29A.

[0235] Further, the placement position can be designated by the user, and the user can freely move the furniture image in the room displayed as the virtual captured image 611. The movement of furniture can be performed by set modeling condition based on the 3D modelling data again, in response to change of the condition of the designated furniture such as the position or the orientation. The user can also select the furniture image to be placed from the furniture images being provided to users by the furniture sales server 601 (the server 202). For example, the user can change colors and sizes of furniture. Also, types of furniture can be changed. For example, a chair can be replaced with a sofa.

[0236] Here, user can remove an object which has already been placed in the room as the displayed virtual captured image 611, and place a designated furniture image at the place where the removed object had been placed. Specifically, the terminal device 201 can discriminate particular object in the virtual captured image 511 by analyzing the virtual captured image. The discrimination can be preformed based on a change of contrast in the virtual captured image, depth data (depth map), and the like, and for example the wall, the column, or the shelf described in the figure 28 are identified as individual object each other. User can designate each identified object, and the terminal device can generate an image which is the virtual captured image without the designated object, in response to user instruction for the designated object. The place where the removed object has been placed in the virtual captured image can be represented as an extended plane of the floor or the wall simulated based on the depth data (depth map) 612, or represented by change of the condition of the object to display translucent condition. So that user can confirm a situation of the room, the designated object of which is removed, or is replaced to designated furniture after the removal.

[0237] The number of pieces of furniture to be combined with the virtual captured image is not fixed, and may be one or more. The terminal device 201 can also cause the server 202 or the like to record the image data of the combined image showing the result of the placement of the furniture image. Accordingly, the user can readily recheck the result of the placement of the furniture image later.

[0238] As the furniture sales support application is executed in the terminal device 201, for example, the user can receive the furniture sales support service. That is, before purchasing the furniture, the user can virtually place virtual furniture (a furniture

image) in the place (such as a room) to be furnished with the furniture (or can simulate placement of the furniture). Accordingly, the user can eliminate the anxiety about the purchase of the furniture before actually purchasing, and the motivation to purchase can be increased. In short, the multiview-image using service providing system 200 can support sales of furniture by providing the above described furniture sales support service.

[0239] <Functional Blocks>

The terminal device 201 has functions shown as functional blocks in Fig. 30A, as the CPU 221 executes a predetermined program. As shown in Fig. 30A, the CPU 221 has functional blocks such as a user instruction reception processing unit 651, a display control unit 652, an imaging control unit 653, a metadata generation unit 654, a depth detection unit 655, a virtual captured image generation unit 656, a furniture image placement processing unit 657, a purchase processing unit 658, a file generation unit 659, a combined image data generation unit 660, an application parameter generation unit 661, and a transmission control unit 662.

[0240] The user instruction reception processing unit 651 controls the input unit 231 or the like, to perform a process related to reception of a user instruction. The display control unit 652 controls the output unit 232 or the like, to perform a process related to display control to display an image such as a GUI or a guide on a monitor. The imaging control unit 653 performs a process related to multiview imaging control. The metadata generation unit 654 performs a process related to generation of metadata of a multiview image obtained by multiview imaging. The depth detection unit 655 performs a process related to detection of the depth of the multiview image. The virtual captured image generation unit 656 performs a process related to generation of a virtual captured image. The furniture image placement processing unit 657 performs a process related to the placement of a furniture image in the virtual captured image. The purchase processing unit 658 performs a process related to a purchase of furniture. The file generation unit 659 performs a process related to generation of a multiview image file. The combined image data generation unit 660 performs a process related to generation of combined image data in which the furniture image is combined with the virtual captured image. The application parameter generation unit 661 performs a process related to generation of application parameters about the application. The transmission control unit 662 controls the communication unit 234 or the like, to perform a process related to transmission of various kinds of information.

[0241] Meanwhile, the server 202 has functions shown as functional blocks in Fig. 30B, as the CPU 251 executes a predetermined program. As shown in Fig. 30B, the CPU 251 has functional blocks such as a user management unit 671, an application selection unit 672, a furniture data selection unit 673, a purchase processing unit 674, an acquisition

control unit 675, and a data management unit 676.

[0242] Like the user management unit 291, the user management unit 671 performs a process related to management of users to whom multiview-image using services are to be provided. The application selection unit 672 controls the communication unit 264 to communicate with the terminal device 201 or the like, and performs a process related to selection of the application to be executed. The furniture data selection unit 673 controls the communication unit 264 or the like to communicate with the terminal device 201, and performs a process related to selection of the furniture (furniture image) to be placed in a virtual captured image. The purchase processing unit 674 controls the communication unit 264 or the like to communicate with the terminal device 201 and the furniture sales server 601, and performs a process related to a purchase of furniture. The acquisition control unit 675 controls the communication unit 264 or the like, to perform a process related to acquisition of various kinds of data transmitted from the terminal device 201 or the like. Like the data management unit 295, the data management unit 676 performs a process related to management of data such as a multiview image file, and management of an application and data related to the application.

[0243] Further, the furniture sales server 601 has functions shown as functional blocks in Fig. 30C, as the CPU 411 executes a predetermined program. As shown in Fig. 30C, the CPU 411 has functional blocks such as a furniture data provision unit 681 and a purchase processing unit 682.

[0244] The furniture data provision unit 681 performs a process related to provision of the data to be used in the furniture sales support, such as a furniture image and 3D modeling data. The purchase processing unit 682 controls the communication unit 424 or the like to communicate with the server 202, and performs a process related to a furniture purchase procedure.

[0245] <Flow of a Multiview-Image Using Service Providing Process>

The terminal device 201, the server 202, and the furniture sales server 601 of the multiview-image using service providing system having the above described structure perform a multiview-image using service providing process to provide a service using multiview images, or provide a product sales support service in this embodiment. Referring now to the flowchart shown in Figs. 31 through 33, an example flow of the multiview-image using service providing process to be performed by those devices is described.

[0246] In step S321, the furniture data provision unit 681 of the furniture sales server 601 supplies the image data of a furniture image and the 3D modeling data thereof to the server 202, and registers the image data and the 3D modeling data therein. In step S311, the data management unit 676 of the server 202 acquires those data, and

registers and manages those data as the data of the furniture being promoted.

[0247] In step S301, the user instruction reception processing unit 651 of the terminal device 201 controls the input unit 231 or the like, to receive an instruction to request startup of an application from a user. The transmission control unit 662 controls the communication unit 234 or the like, to supply the application startup request received by the user instruction reception processing unit 651 to the server 202.

[0248] In step S312, the application selection unit 672 of the server 202 controls the communication unit 264 or the like, to acquire the request. In step S313, the application selection unit 672, in response to the request, generates a list of applications that can be used by the user based on the user management information being managed by the user management unit 671, and controls the communication unit 264 or the like, to supply the list to the terminal device 201.

[0249] In step S302, the transmission control unit 662 of the terminal device 201 controls the communication unit 234 or the like, to acquire the list. The display control unit 652 controls the output unit 232, to display the acquired list as an image on a monitor. The user then selects the application to be started from the list.

[0250] In step S303, the user instruction reception processing unit 651 controls the input unit 231 or the like, to receive an instruction as to the selection of the application to be started from the user. The transmission control unit 662 controls the communication unit 234 or the like, to supply the application-to-start selection instruction received by the user instruction reception processing unit 651 to the server 202.

[0251] In step S314, the application selection unit 672 of the server 202 controls the communication unit 264 or the like, to acquire the selection instruction. In step S315, the furniture data selection unit 673 generates a product list that is a list of the pieces of furniture that can be sold to the user based on the user management information being managed by the user management unit 671, and controls the communication unit 264 or the like, to supply the list to the terminal device 201.

[0252] In step S304, the transmission control unit 662 of the terminal device 201 controls the communication unit 234 or the like, to acquire the list. The display control unit 652 controls the output unit 232, to display the acquired list as an image on a monitor. The user then selects the furniture (furniture data) to be the current furniture data from the list.

[0253] In step S305, the user instruction reception processing unit 651 controls the input unit 231 or the like, to receive a furniture data selection instruction from the user. The transmission control unit 662 controls the communication unit 234 or the like, to supply the furniture data selection instruction received by the user instruction reception processing unit 651 to the server 202.

[0254] In step S316, the furniture data selection unit 673 of the server 202 controls the com-

munication unit 264 or the like, to acquire the selection instruction.

[0255] In step S306, the imaging control unit 653 of the terminal device 201 that has supplied the furniture data selection instruction controls the imaging unit 236 to perform multiview imaging. In step S307, the metadata generation unit 654 generates the metadata to be associated with the multiview image generated in step S306. The contents of the metadata are not fixed, but the metadata may include information such as the camera array information 342 and the viewpoint number information 343 as described above with reference to Fig. 11.

[0256] In step S308, the depth detection unit 655 detects the depth value of the multiview image, and generates depth data (a depth map). The depth detection unit 655 generates the depth data by performing the depth detection process described above with reference to Fig. 14, for example. In step S309, the virtual captured image generation unit 656 generates a virtual captured image by using the multiview image.

[0257] Referring now to Fig. 32, when the image data of the furniture image and the 3D modeling data thereof are updated, the furniture data provision unit 681 of the furniture sales server 601 in step S351 controls the communication unit 424 or the like, to supply those data to the server 202 by a background transfer as appropriate. In step S341, the data management unit 676 of the server 202 acquires those data, and updates the registered information.

[0258] In step S342, in accordance with the furniture data selection instruction acquired in step S316, the furniture data selection unit 673 of the server 202 controls the communication unit 264 or the like, to provide the image data of the selected furniture and the 3D modeling data thereof to the terminal device 201. In step S331, the transmission control unit 662 of the terminal device 201 controls the communication unit 234, to acquire the image data of the furniture and the 3D modeling data.

[0259] In step S343, the furniture data selection unit 673 of the server 202 also selects a piece of furniture (in a different color or a different size) highly related to the furniture indicated by the furniture data provided in step S342, and controls the communication unit 264 or the like, to supply a furniture image of the selected furniture, the 3D modeling data thereof, and the like to the terminal device 201 by a background transfer as appropriate. In step S332, the transmission control unit 662 of the terminal device 201 controls the communication unit 234, to acquire the image data of the furniture and the 3D modeling data thereof.

[0260] As the furniture-related data is transmitted to the terminal device 201 by a background process without a request from the terminal device 201, the user of the terminal device 201 can replace the furniture image placed in a virtual captured image with an image of a highly-related piece of furniture, without a time lag in the communication for data acquisition.

[0261] In step S333, the furniture image placement processing unit 657 of the terminal device 201 performs a furniture image placement process to place the furniture image that is an example of an object in the virtual captured image that is an example of a background image. In doing so, the furniture image placement processing unit 657 sets the size and the orientation of the furniture image in accordance with the placement position of the furniture image. If the furniture image and the 3D modeling data need to be changed, or a furniture image and 3D modeling data need to be added as a result of the furniture image placement process, the furniture image placement processing unit 657 in step S334 controls the communication unit 234 or the like, to request the server 202 to change furniture images and 3D modeling data or add a furniture image and 3D modeling data.

[0262] In step S344, the furniture data selection unit 673 of the server 202 controls the communication unit 264 or the like, to acquire the request. In step S345, in response to the request, the furniture data selection unit 673 controls the communication unit 264 or the like, to provide an image data of the selected furniture and the 3D modeling data thereof to the terminal device 201. In step S335, the transmission control unit 662 of the terminal device 201 controls the communication unit 234, to acquire the image data of the furniture and the 3D modeling data thereof.

[0263] In step S345, the furniture data selection unit 673 of the server 202 also selects a piece of furniture (in a different color or a different size) highly related to the furniture indicated by the furniture data provided in step S344, and controls the communication unit 264 or the like, to supply a furniture image of the selected furniture, the 3D modeling data thereof, and the like to the terminal device 201 by a background transfer as appropriate. In step S336, the transmission control unit 662 of the terminal device 201 controls the communication unit 234, to acquire the image data of the furniture and the 3D modeling data.

[0264] As the furniture-related data is transmitted to the terminal device 201 by a background process without a request from the terminal device 201, the user of the terminal device 201 can replace the furniture image placed in a virtual captured image with an image of a highly-related piece of furniture, without a time lag in the communication for data acquisition.

[0265] Referring now to Fig. 33, the user of the terminal device 201 determines whether to purchase furniture based on the above described furniture placement simulation. In step S361, the user instruction reception processing unit 651 controls the input unit 231 or the like, to receive a user instruction, and determines which piece of furniture is to be purchased in accordance with the instruction.

[0266] In step S362, the purchase processing unit 658 of the terminal device 201 controls the communication unit 234 or the like to communicate with the server 202, and

performs a process related to the purchase, such as a payment process. In step S371, the purchase processing unit 674 of the server 202 controls the communication unit 264 or the like to communicate with the terminal device 201 and the furniture sales server 601, and performs a process related to the purchase, such as a payment process. In step S381, the purchase processing unit 682 of the furniture sales server 601 controls the communication unit 424 or the like to communicate with the terminal device 201 and the server 202, and performs a process related to the purchase, such as a payment process.

[0267] In step S363, the file generation unit 659 of the terminal device 201 generates a multiview image file. The format of the multiview image file may be of any type. In a case where the multiview image is a still image, for example, the multiview image may be turned into a file in the Exif file format. In a case where the multiview image is a moving image, for example, the multiview image may be turned into a file in the MP4 file format. It is of course possible to use a file format other than the above.

[0268] In step S364, the combined image data generation unit 660 generates the data of a combined image (combined image data) formed by placing and combining the furniture image with the virtual captured image in accordance with a user instruction.

[0269] In step S365, the application parameter generation unit 661 generates the application parameters of the application for performing the product sales support. The application parameters are history information that indicates which values have been set for which parameters, what kinds of operations (instructions) have been conducted by the user, and what kinds of processes have been performed in this furniture sales support.

[0270] In step S366, the transmission control unit 662 controls the communication unit 234, to supply the various kinds of data (the multiview image file (the multiview image data, the depth data, the metadata, and the like), the combined image data, the application parameters, and the like) generated in the above described manner, to the server 202.

[0271] In step S372, the acquisition control unit 675 of the server 202 controls the communication unit 264, to acquire the various kinds of data.

[0272] In step S373, the data management unit 676 stores the various kinds of data acquired in step S372, and registers the various kinds of data with the user (or causes the user management information to reflect the various kinds of data).

[0273] When the processing in step S373 is finished, the multiview-image using service providing process comes to an end.

[0274] As such a multiview-image using service providing process is performed, a user can perform a furniture placement simulation more easily by using a multiview image. Also, generated combined image data is registered with the user and is managed in the server 202. Accordingly, the user can readily recheck the result of furniture placement.

That is, the multiview-image using service providing system 200 (the multiview-image using service platform 100) can increase the user-friendliness of the multiview-image using service.

[0275] <Flow of the Furniture Image Placement Process>

Referring now to the flowchart shown in Fig. 34, an example flow of the furniture image placement process performed in step S333 in Fig. 32 is described in detail.

[0276] When the furniture image placement process is started, the furniture image placement processing unit 657 in step S391 controls the input unit 231, for example, to receive a placement position designation from the user or the like.

[0277] In step S392, the furniture image placement processing unit 657 sets the orientation and the size of the furniture image in the position where the furniture image is placed in the virtual captured image based on the depth data and the base-line length information about the virtual captured image (multiview image) as an example of a background image, and the 3D modeling data of the furniture image as an example of an object.

[0278] In step S393, the furniture image placement processing unit 657 places the furniture image having the orientation and the size set in step S392 in the position designated (by the placement position designation received in step S391, for example) in the virtual captured image, and combines the furniture image with the virtual captured image.

[0279] When the processing in step S393 is finished, the furniture image placement process comes to an end, and returns to the process shown in Fig. 32.

[0280] As the furniture image placement process is performed in the above described manner, a user can more readily perform a furniture placement simulation.

[0281] The above described furniture image placement process is not necessarily performed by the terminal device 201, but may be performed by some other device. For example, the furniture image placement process may be performed by the server 202. In that case, the CPU 251 of the server 202 includes the necessary functional blocks such as the furniture image placement processing unit 657. In that case, the furniture image placement process can be performed basically in the same manner as in the above described example. The information that is to be used in the furniture image placement process and is obtained by the terminal device 201, such as a multiview image file, is transmitted to the server 202 where necessary, under the control of the transmission control unit 662.

[0282] Likewise, the furniture image placement process may be performed in a device (such as the terminal device 401) other than the terminal device 201 that performs multiview imaging and the server 202, for example. In that case, the CPU of the device includes the necessary functional blocks such as the furniture image placement processing unit

657. In that case, the furniture image placement process can be performed basically in the same manner as in the above described example. The information that is to be used in the furniture image placement process and is obtained by the terminal device 201 or the server 202, such as a multiview image file and furniture data, is transmitted to the device where necessary, under the control of the transmission control unit 662, the furniture data selection unit 673, or the like.

[0283] <Furniture Placement Updating Process>

If the placement position designation is updated in the above described product sales support application, the furniture image combining position may be changed in accordance with the update. For example, as shown in Fig. 35A, in a case where the placement position designation for a furniture image 702A placed in a virtual captured image 701 is updated as indicated by a dashed arrow 703, the size and the orientation of the furniture image 702A are reset in accordance with the updated placement position (a furniture image 702B).

[0284] In a case where the viewpoint of a virtual captured image is updated, the position of the placed furniture image is not updated, and a condition of the furniture image having an appropriate size and an appropriate orientation is relocated in the original position in the virtual captured image with the new viewpoint. For example, as shown in Fig. 35B, a sofa 706 is placed in a virtual captured image formed by capturing an image of a room 704 from a viewpoint 705A. When the viewpoint of the virtual captured image is moved to a viewpoint 705B, the sofa 706 is also shown in the virtual captured image with the updated viewpoint. Therefore, the sofa 706 is placed in the original position in the virtual captured image with the updated viewpoint. At this point, the orientation and the size of the sofa 706 are adjusted appropriately in the virtual captured image with the updated viewpoint.

[0285] To realize such a function, the furniture image placement processing unit 657 performs a furniture placement updating process. Referring now to the flowchart shown in Fig. 36, an example flow of the furniture placement updating process is described. When the furniture placement updating process is started, the furniture image placement processing unit 657 in step S401 determines whether the designated placement position has been changed. If it is determined that a new placement position designation has been received from the user via the input unit 231, and the placement position designation has been changed, for example, the process moves on to step S402.

[0286] In step S402, the furniture image placement processing unit 657 sets the orientation and the size of the furniture image based on depth data and base-line length information as well as 3D modeling data. In step S403, the furniture image placement processing unit 657 combines the furniture image with the virtual captured image in

the updated designated position.

[0287] When the processing in step S403 is finished, the process moves on to step S404. If the designated placement position is determined not to have been changed in step S401, the process also moves on to step S404.

[0288] In step S404, the furniture image placement processing unit 657 determines whether the imaging position or direction has been changed. For example, in a case where a new virtual captured image is generated by new multiview imaging, or where multiview imaging is performed to capture a moving image while the operator is in motion, the imaging position or direction is determined to have been changed. In that case, the process moves on to step S405.

[0289] In step S405, the furniture image placement processing unit 657 updates the virtual captured image by re-creating a virtual captured image from a new multiview image. In step S406, the furniture image placement processing unit 657 identifies the position of the furniture image placed before the virtual captured image update in the updated virtual captured image. In step S407, the furniture image placement processing unit 657 sets the size and the orientation of the furniture image in the position specified in step S406 in the updated virtual captured image. In step S408, the furniture image placement processing unit 657 relocates the furniture image having the size and the orientation set in step S407 in the position specified in step S406 in the updated virtual captured image.

[0290] When the processing in step S408 is finished, the furniture placement updating process comes to an end. Also, if the imaging position or direction is determined not to have been changed in step S404, the furniture placement updating process comes to an end.

[0291] After a furniture image is placed in a virtual captured image, this furniture placement updating process is repeated until the furniture placement simulation is finished. Accordingly, a furniture image having an appropriate size and an appropriate orientation can be typically combined with a virtual captured image in an appropriate position.

[0292] <Floor Contact Determination>

As for the position of a furniture image, a check may be made to determine whether the furniture image is in contact with the floor or the like in a virtual captured image. For example, in the virtual captured image 711 shown in Fig. 37A, the position of a light stand 712 is designated in the position shown in Fig. 37A. In this case, the light stand 712 is at a distance from a floor 714 as indicated by a dashed double-headed arrow 713, and is placed in the air. This is not a realistic placement position, and is inappropriate and undesirable as a furniture placement simulation.

[0293] In such a case, the placement position of the light stand 712 may be changed so that the light stand 712 is brought into contact with the floor 714 in the virtual captured

image 711 as shown in Fig. 37B. Alternatively, the position may not be changed, but an alarm may be issued to the user or the like.

[0294] To realize such a function, the furniture image placement processing unit 657 performs a floor contact determination process. Referring now to the flowchart shown in Fig. 38, an example flow of the floor contact determination process is described.

[0295] When the floor contact determination process is started, the furniture image placement processing unit 657 in step S421 identifies the height of the designated placement position of the furniture from an area such as a floor on which furniture can be placed. In step S422, the furniture image placement processing unit 657 determines whether the furniture image is in contact with the area such as a floor on which furniture can be placed based on the 3D modeling data of the placed furniture image. If the furniture image is not in contact with the area, the process moves on to step S423.

[0296] In step S423, the furniture image placement processing unit 657 performs error processing. The contents of the error processing are not fixed, and any processing may be performed. For example, the furniture image may be moved so as to be in contact with the floor based on update of the modeling condition of the 3D modeling data, as described above. Alternatively, the placement position of the furniture image may not be updated, but an alarm may be issued to the user or the like, as described above.

[0297] When the processing in step S423 is finished, the floor contact determination process comes to an end. If the furniture image is determined to be in contact with the area such as a floor on which furniture can be placed in step S422, the floor contact determination process also comes to an end.

[0298] Every time furniture is placed, the floor contact determination process is performed. As a result, a user can perform a more realistic furniture placement simulation.

[0299] The placement position of an object may be adjusted not only in the vertical direction as described above, but also in the horizontal direction (including the transverse direction and the depth direction) of the object based on the contents of the background image (the positions of objects included in the background image).

[0300] For example, the background image (a virtual captured image) is an image of a room in which there is a large pillar in the front, there is a space behind the pillar, and there is a wall behind the space. In front of the wall (in the room), the area of the pillar is a placement prohibited area for objects (furniture images), and the space between the pillar and the wall is a placement allowed area for objects (furniture images). In a case where there is an instruction to place a furniture image in the placement prohibited area, the furniture image is moved to the space between the pillar and the wall, which is the placement allowed area, and is then placed therein. At this point, not only the size and the orientation of the furniture image are adjusted in accordance with the placement position after the move, but also part or all of the furniture image is

processed so as to be hidden behind the pillar and be combined with the virtual captured image, if necessary.

[0301] As a result, a user can perform a more realistic furniture placement simulation.

[0302] <Length Measurement>

Further, length measurement may be carried out in a virtual captured image. As shown in Fig. 39, in a virtual captured image 721, the width of a window is measured as indicated by a dashed double-headed arrow 722, for example. In the virtual captured image 721, the size of the window varies with the distance to the window in the depth direction. Therefore, a measured length may be corrected in accordance with the distance in the depth direction by using the depth data and the base-line length information about a multiview image, for example.

[0303] To realize such a function, the furniture image placement processing unit 657 performs a measurement process. Referring now to the flowchart shown in Fig. 40, an example flow of the measurement process is described.

[0304] When the measurement process is started, the furniture image placement processing unit 657 in step S441 receives a designation of an area in a virtual captured image. After an area is designated, the furniture image placement processing unit 657 in step S442 measures the length of the area based the depth data and the base-line length information about the multiview image used in generating the virtual captured image. When the processing in step S442 is finished, the measurement process comes to an end.

[0305] By this process, the length (the dashed double-headed arrow 722) of the window in the horizontal direction can be more accurately measured in the virtual captured image 721 in Fig. 39, for example. Accordingly, when curtains for this window are to be purchased, errors in the measurement of the size of the curtains can be reduced, and a decrease in the user's motivation to purchase can be prevented. That is, sales can be supported by such a service.

[0306] <Lighting Process>

Also, lighting (light rays) may be reproduced in a virtual captured image. As shown in Fig. 41, a situation where a floor lamp 732 placed in a virtual captured image 731 is on may be reproduced, for example.

[0307] To realize such a function, the furniture image placement processing unit 657 performs a lighting process. Referring now to the flowchart shown in Fig. 42, an example flow of the lighting process is described.

[0308] When the lighting process is started, the furniture image placement processing unit 657 in step S461 receives designations of light source parameters including parameters related to the light source, such as color, luminance, and direction. The values of the respective parameters included in the light source parameters may be designated by a

user, or may be provided as furniture data associated with an image of the furniture (a lighting device). In step S462, the furniture image placement processing unit 657 simulates lighting (light rays from the light source) in a virtual captured image based on the designated light source parameters. In step S463, the furniture image placement processing unit 657 causes the virtual captured image to reflect the result of the simulation. For example, the portion illuminated with light is made brighter, and the portion that is not illuminated with light is made darker or shaded.

[0309] As a result, a user can perform a more realistic lighting placement simulation. Accordingly, when a lighting device is purchased, inconvenient differences between the color and brightness of the actually purchased lighting device and estimated color and brightness of the product displayed in the store or shown in a catalog can be reduced. In this manner, a decrease in the user's motivation to purchase can be prevented. That is, sales can be supported by such a service.

[0310] <Line-of-Flow Presentation Process>

Also, portions to be lines of flow may be emphasized in a virtual captured image. As shown in Fig. 43, a table 742 is placed in a virtual captured image 741, and a portion 743 that satisfies line-of-flow conditions is identified, for example. This portion may be presented to the user. In the example shown in Fig. 43, the portion 743 that satisfies the line-of-flow conditions is emphasized by the shading. The line-of-flow conditions may be that a person can stand on the floor, and a large enough width to allow a person to walk through the place is ensured, for example.

[0311] The portion 743 satisfying the line-of-flow conditions may be indicated by a color or luminance, or may be indicated by a symbol or a figure such as an arrow or a star.

[0312] To realize such a function, the furniture image placement processing unit 657 performs a line-of-flow presentation process. Referring now to the flowchart shown in Fig. 44, an example flow of the line-of-flow presentation process is described.

[0313] When the line-of-flow presentation process is started, the furniture image placement processing unit 657 in step S481 identifies a floor portion having a width equal to or greater than a predetermined width in a virtual captured image, or a portion that satisfies the line-of-flow conditions, based on base-line length information. In step S482, the furniture image placement processing unit 657 emphasizes the identified portion with a pattern, a color, luminance, or the like. When the processing in step S482 is finished, the line-of-flow presentation process comes to an end.

[0314] In this manner, a user can simulate a furniture layout so as to secure a line of flow when placing furniture. Accordingly, inconvenience such as a space that is too narrow for a person to walk through due to large furniture can be prevented, for example. Also, a check can be made to determine whether a wide enough space for a wheel chair can be secured before the purchase of furniture, for example. Accordingly, the user's

motivation to purchase is increased by such a service, and sales can be supported.

[0315] <Human Image Placement>

When furniture is placed, a human image may be placed in a virtual captured image. As shown in Fig. 45, a chair 752 is placed in a virtual captured image 751, and a human image 753 may be placed in its vicinity, for example. This human image may be a captured image of an actual person, or may be an image of a fictional person. In either way, this human image is associated with the same 3D modeling data as that of a furniture image.

[0316] To realize such a function, the furniture image placement processing unit 657 performs a human image placement process. Referring now to the flowchart shown in Fig. 46, an example flow of the human image placement process is described.

[0317] When the human image placement process is started, the furniture image placement processing unit 657 in step S501 receives a position designation for the placement position of a human image from a user or the like via the input unit 231 or the like. In step S502, the furniture image placement processing unit 657 sets the size and the orientation of the human image in the designated position based on the base-line length information and the depth data of the captured image used in generating the virtual captured image, as in the case of a furniture image. In step S503, the furniture image placement processing unit 657 places the human image having the size and the orientation set in step S502 in the designated position (designated in step S501, for example). When the processing in step S503 is finished, the human image placement process comes to an end.

[0318] In this manner, a user can place not only a furniture image but also a human image in a virtual captured image. Accordingly, furniture placed in a position can be compared with the human image, and the size and the style of the furniture can be more accurately expressed. As a result, inconvenience such as differences in size and impression between the actually purchased furniture and expectations can be reduced, for example. Accordingly, the user's motivation to purchase is increased by such a service, and sales can be supported.

[0319] The position of the human image can be set in any appropriate manner. For example, the placement position of the human image may be determined in accordance with the position of the furniture image, and the human image may be placed on or near the furniture image. Alternatively, a user may designate a furniture image, and a human image may be placed in a position in accordance with the designated furniture image, for example. The human image to be placed may be an image of one person or an image of more than one person.

[0320] Here, a human image is an example of an image to be combined with (or placed in) a background image (a virtual captured image, for example), and is not an object (a

furniture image, for example) to be promoted. In other words, an image other than a human image may be placed in the same manner as in the above described case of a human image. For example, it is possible to use an image of an animal such as a dog or a cat (an animal image), an image of a product that is not being sold (promoted) (a product image), or an image of a person and an animal (a combination image).

[0321] Further, when an image is to be placed in the above manner, a user or the like may be allowed to select the image to be placed. For example, a user may be allowed to select a human image, an animal image, a product image, a combination image, or the like. Even more specific selection may be allowed. In the case of a human image, sex, age, posture (standing, sitting, or the like), clothes, the number of persons, and the like may be selected, for example. Likewise, in the case of an animal image, a product image, or a combination image, parameters such as category, sex, age, size, and color can be selected. An image is selected in any appropriate manner. For example, a user or the like may be allowed to select a desired image from candidates that are prepared in advance. Alternatively, a user or the like may create an image to be combined like the above described human image by processing an image or combining images.

[0322] <Restriction on a Furniture List>

As described above, a furniture list is presented when a user selects the furniture to be placed. At that point, a list of the pieces of furniture that can be placed in a virtual captured image may be presented to the user. Specifically, pieces of furniture that are not to be placed in a virtual captured image may be eliminated from the list, and a user or the like may select a furniture image to be placed in the virtual captured image (a background image) from the furniture images (objects) that can be placed in the virtual captured image.

[0323] To realize such a function, the furniture image placement processing unit 657 performs a furniture list restriction process. Referring now to the flowchart shown in Fig. 47, an example flow of the furniture list restriction process is described.

[0324] When the furniture list restriction process is started, the furniture image placement processing unit 657 in step S521 determines the sizes of furniture that can be placed in a virtual captured image from the base-line length information about the multiview image used in generating the virtual captured image. In step S522, the furniture image placement processing unit 657 identifies pieces of furniture that can be placed in the virtual captured image based on the 3D modeling data of the furniture images in a list supplied from the server 202. In step S523, the furniture image placement processing unit 657 creates a list of the pieces of furniture identified in step S522. The display control unit 652 controls the output unit 232, to display the list created by the furniture image placement processing unit 657 as an image on a monitor. When the processing in step S523 is finished, the furniture list restriction process comes to an end.

[0325] In this manner, unnecessary pieces of furniture can be eliminated from the list to be presented to the user. Accordingly, the user can select furniture by referring to the more useful list. Particularly, in a case where there are a large number of pieces of furniture being sold and a large number of kinds of furniture being sold, it might be difficult for a user to select a piece of furniture from the list. Therefore, it is preferable to eliminate the largest possible amount of unnecessary information from the list. Accordingly, furniture selection can be made easier for the user, a decrease in the motivation to purchase can be prevented, and sales can be supported.

[0326] In the above description, a virtual captured image obtained by multiview imaging and a furniture image are combined to form an example of a combined image. However, any images may be combined with each other. For example, captured images may be combined with each other, artificial images such as computer graphic images may be combined with each other, or a captured image and an artificial image may be combined with each other. Also, captured images that are partially artificial may be combined with each other. Further, moving images may be combined with each other, still images may be combined with each other, or a moving image and a still image may be combined with each other.

[0327] In the above description, in a product support service, an object is combined with a background image. However, the object may be of any kind, as long as it is an image of a product that can be promoted. The object may not have 3D modeling data. For example, 3D modeling data may be provided from a different site from the object. Also, instead of 3D modeling data, simplified information that indicates a size or the like may be used, for example.

[0328] A background image is an image in which an object is to be placed, and is not an image that indicates the superimposition relationship (positional relationship) with respect to the object. For example, the background image may include a foreground to be superimposed on the front side of an object. Also, the background image may be formed with only the foreground (that is, the entire background is to be superimposed on the front side of the object). Further, the background image may be the foreground or the background of the object, depending on the position in which the object is placed. That is, the background image may be formed with more than one image (or may be formed by superimposing images on each other). As described above, while the background image is formed with one captured image (a virtual captured image), the object and the background image may be processed as appropriate and be then combined, so that part of the background image comes in front of the object, depending on the placement position (particularly, the position in the depth direction) of the object (a furniture image).

[0329] <6. Others>

It should be noted that the above described series of processes may be performed by hardware or may be performed by software. In a case where the above described series of processes are performed by software, the program forming the software is installed from a network or a recording medium.

[0330] This recording medium is formed with a removable medium (such as the removable medium 241, the removable medium 271, or the removable medium 431) that is distributed for delivering the program to users independently of the device, and has the program recorded therein, as shown in Figs. 4, 6, and 16, for example. This removable medium may be a magnetic disk (a flexible disk) or an optical disk (a CD-ROM or a DVD). Further, the removable medium may be a magnetooptical disk (a MD (Mini Disc), a semiconductor memory, or the like.

[0331] In this case, the program can be installed into a storage unit via an input/output interface when the removable medium is mounted in the drive.

[0332] Alternatively, this program can be provided via a wired or wireless transmission medium such as a local area network, the Internet, or digital satellite broadcasting. In that case, the program can be received by the communication unit (the communication unit 234, the communication unit 264, or the communication unit 424, for example) of each device, and be installed into the storage unit (the storage unit 233, the storage unit 263, or the storage unit 423, for example) of each device.

[0333] Alternatively, this program can be installed into the ROM (the ROM 222, the ROM 252, or the ROM 412, for example) of each device, and be installed beforehand into the storage unit (the storage unit 233, the storage unit 263, or the storage unit 423, for example) of each device.

[0334] The programs to be executed by the computer may be programs for performing processes in chronological order in accordance with the sequence described in this specification, or may be programs for performing processes in parallel or performing a process when necessary, such as when there is a call.

[0335] In this specification, the steps written in the programs recorded in a recording medium include not only processes to be performed in chronological order in accordance with the sequence described herein, but also processes to be performed in parallel or independently of one another if not necessarily in chronological order.

[0336] The processing in each of the above described steps can be performed by each of the above described devices or any appropriate device other than the above described devices. In that case, the device that performs the processing include the above described necessary functions (such as functional blocks) for performing the processing. Also, the necessary information for the processing is transmitted to the device where necessary.

[0337] In this specification, a system means an assembly of components (devices, modules

(parts), and the like), and not all the components need to be provided in the same housing. In view of this, devices that are housed in different housings and are connected to each other via a network form a system, and one device having modules housed in one housing is also a system.

[0338] Also, in the above described examples, any structure described as one device (or one processing unit) may be divided into two or more devices (or processing units). Conversely, any structure described as two or more devices (or processing units) may be combined to form one device (or one processing unit). Also, it is of course possible to add a structure other than the above described ones to the structure of any of the devices (or any of the processing units). Further, as long as the structure and function of the entire system remain the same, part of the structure of a device (or a processing unit) may be incorporated into another device (or another processing unit).

[0339] Although embodiments of the present disclosure have been described above with reference to the accompanying drawings, the present disclosure is not limited to those examples. It is apparent that those who have ordinary skills in the art can make various changes or modifications within the scope of the technical spirit claimed herein, and it should be understood that those changes or modifications are within the technical scope of the present disclosure.

[0340] For example, the present technique can be embodied in a cloud computing structure in which one function is shared among devices via a network, and processing is performed by the devices cooperating with one another.

[0341] The respective steps described with reference to the above described flowcharts can be carried out by one device or can be shared among devices.

[0342] In a case where more than one process is included in one step, the processes included in the step can be performed by one device or can be shared among devices.

[0343] The image processing device according to the above described embodiments can be applied to various electronic devices including: transmitters and receivers for satellite broadcasting, cable broadcasting such as cable television, deliveries via the Internet, deliveries to terminals by cellular communications, and the like; recording devices that record images on media such as optical disks, magnetic disks, or flash memories; or reproducing devices that reproduce images from those storage media.

[0344] The present technique is not limited to the above, and can be applied to any component mounted on such a device or devices constituting a system, such as a processor as a system LSI (Large Scale Integration) or the like, a module using processors and the like, a module using processors and the like, a unit using modules and the like, or a set (as a component of a device) having functions as well as the functions of a unit.

[0345] The present technique can also be in the following forms.

(1) An image processing apparatus, including:
circuitry configured to initiate a setting of an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object.
(2) The image processing apparatus of any of (1) and (3) through (22), wherein the circuitry is further configured to initiate a changing of a condition of the object to a condition corresponding to a second position, based on a change of position at which the object is set from a first position to the second position.
(3) The image processing apparatus of any of (1), (2) and (4) through (22), wherein the circuitry is further configured to initiate a changing of a condition of the object from a condition associated with a first viewpoint to a condition associated with a second view point, based on a changing of a viewpoint of the background image from the first viewpoint to the second viewpoint.
(4) The image processing apparatus of any of (1) through (3) and (5) through (22), wherein the circuitry is further configured to initiate a changing of a condition of the object from a condition associated with a first viewing direction to a condition associated with a second viewing direction, based on a changing of a direction of a viewpoint of the background image from the first viewing direction to the second viewing direction.
(5) The image processing apparatus of any of (1) through (4) and (6) through (22), wherein the circuitry is further configured to initiate a moving of the object, and repositioning of the object to have a condition of making contact with a plane of the background image.
(6) The image processing apparatus of any of (1) through (5) and (7) through (22), wherein the condition of making contact with the plane is determined based on a distance between the object and the plane.
(7) The image processing apparatus of any of (1) through (6) and (8) through (22), wherein a condition of the object is a condition associated with a position and an orientation of the object.
(8) The image processing apparatus of any of (1) through (7) and (9) through (22), wherein the circuitry is further configured to initiate a simulation of a lighting in the background image based on light source parameters and the depth data, the light source parameters being parameters related to a light source.
(9) The image processing apparatus of any of (1) through (8) and (10) through (22), wherein the circuitry is further configured to initiate an identification of a portion that satisfies line-of-flow conditions in the background image having the object placed therein, and initiates an emphasizing of the identified portion.

(10) The image processing apparatus of any of (1) through (9) and (11) through (22), wherein the circuitry is further configured to initiate a setting of an image of a person within the background image, in accordance with a modeling condition associated with a position at which the image of the person is set within the background image having the object placed therein, and based on the depth data, the base-line length information, and modeling data of the image of the person.

(11) The image processing apparatus of any of (1) through (10) and (12) through (22), wherein the object is selected from among one or more candidate objects, in accordance with a modeling condition of the selected object associated with a position at which the selected object is set in the background image, and based on the depth data, the base-line length information, and the modeling data of the selected object.

(12) The image processing apparatus of any of (1) through (11) and (13) through (22), wherein the one or more candidate objects are objects that can be placed within the background image.

(13) The image processing apparatus of any of (1) through (12) and (14) through (22), wherein the circuitry is further configured to initiate a control of a capturing of an image of a subject, initiate an obtaining of the captured image as the background image, and initiate a generation of depth data of the captured image.

(14) The image processing apparatus of any of (1) through (13) and (15) through (22), wherein the captured image is a multiview image formed with a plurality of images having different viewpoints from one another, and the circuitry is further configured to initiate a generation of depth data of the multiview image, and to initiate a generation of a virtual captured image as the background image based on the multiview image and the depth data, the virtual captured image being obtained by imaging a subject of the multiview image.

(15) The image processing apparatus of any of (1) through (14) and (16) through (22), wherein the object is an image of furniture.

(16)The image processing apparatus of any of (1) through (15) and (17) through (22), wherein the circuitry is further configured to initiate a performing of a purchase process to purchase the furniture that is placed within the background image.

(17) The image processing apparatus of any of (1) through (16) and (18) through (22), wherein the circuitry is further configured to initiate a transmission of multiview image data as data of a multiview image and depth data of the multiview image, the multiview image being formed with a plurality of images having different viewpoints from one another and used for generating the background image.

(18) The image processing apparatus of any of (1) through (17) and (19) through (22), wherein the circuitry is further configured to initiate a generation of image data of the background image having the object set therein, and initiate a transmission of the

generated image data.

(19) The image processing apparatus of any of (1) through (18) and (20) through (22), wherein the circuitry is further configured to initiate a generation of an application parameter that is a parameter related to a combining of the background image and the object, and initiate a transmission of the generated application parameter.

(20) The image processing apparatus of any of (1) through (19), (21) and (22), wherein the circuitry is further configured to initiate a generation of metadata about the multiview image, and initiate a transmission of the generated metadata.

(21) The image processing apparatus of any of (1) through (20) and (22), wherein the metadata includes the base-line length information.

(22) The image processing apparatus of any of (1) through (21), wherein the depth data indicates a distance of depth direction in the background image, and the base-line length information indicates a reference length associated with the background image.

(23) An image processing method including:

setting an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object; and

placing the set object to be displayed at the position within the background image.

(24) An image processing device, including

an object placement unit that sets the orientation and the size of an object in a position in which the object is to be placed in a background image, and places the object having the set orientation and the set size in the designated position in the background image, the orientation and the size being set based on depth data, base-line length information, and the three-dimensional modeling data of the object, the depth data indicating the distance to a subject in the background image, the base-line length information being information indicating a reference length in the background image.

(25) The image processing device of any of (24) and (26) through (42), wherein, when another position is designated after the object is placed in the background image, the object placement unit sets the orientation and the size of the object in the another position, and places the object having the set orientation and the set size in the another position in the background image.

(26) The image processing device of any of (24), (25), and (27) through (42), wherein, when there is a change in the position or the orientation of the viewpoint of the background image, the object placement unit sets the orientation and the size of the object in the position in which the object was placed before the change in the position or the orientation of the viewpoint in the background image not yet having the change in the position or the orientation of the viewpoint, and places the object having the set

orientation and the size in the position in which the object was placed before the change in the position or the orientation of the viewpoint in the background image having the change in the position or the orientation of the viewpoint.

(27) The image processing device of any of (24) through (26) and (28) through (42), wherein the object placement unit moves the object, to bring the object having the set orientation and the set size into contact with the floor.

(28) The image processing device of any of (24) through (27) and (29) through (42), wherein the object placement unit measures the length of a designated area in the background image.

(29) The image processing device of any of (24) through (28) and (30) through (42), wherein the object placement unit simulates lighting in the background image based on light source parameters and the depth data, and causes the background image to reflect the simulated lighting, the light source parameters being parameters related to a light source.

(30) The image processing device of any of (24) through (29) and (31) through (42), wherein the object placement unit identifies a portion that satisfies line-of-flow conditions in the background image having the object placed therein, and emphasizes the identified portion in the background image having the object placed therein.

(31) The image processing device of any of (24) through (30) and (32) through (42), wherein the object placement unit sets the orientation and the size of a person in a position in which an image of the person is to be placed in a background having the object placed therein, and places the image of the person having the set orientation and the set size in the designated position in the background image having the object placed therein, the orientation and the size of the person being set based on the depth data, the base-line length information, and the three-dimensional modeling data of the image of the person.

(32) The image processing device of any of (24) through (31) and (33) through (42), wherein the object placement unit sets the orientation and the size of the object selected from candidates for the object in the position in which the object selected from the candidates for the object is to be placed in the background image, and places the object selected from the candidates for the object having the set orientation and the set size in the designated position in the background image, the orientation and the size of the selected object being set based on the depth data, the base-line length information, and the three-dimensional modeling data of the object selected from the candidates for the object.

(33) The image processing device of any of (24) through (32) and (34) through (42), wherein the object placement unit identifies objects that can be placed in the background image, and selects the object to be placed in the background image from

the identified objects, the objects being identified based on the depth data, the base-line length information, and the three-dimensional modeling data.

(34) The image processing device of any of (24) through (33) and (35) through (42), further including:

an imaging unit that captures an image of the subject, and obtains the captured image as the background image; and

a depth data generation unit that generates the depth data of the captured image obtained by the imaging unit.

(35) The image processing device of any of (24) through (34) and (36) through (42), wherein

the captured image is a multiview image formed with images having different viewpoints from one another,

the depth data generation unit generates the depth data of the multiview image, and

the image processing device further includes a virtual captured image generation unit that generates a virtual captured image as the background image based on the multiview image and the depth data, the virtual captured image being obtained by imaging the subject of the multiview image.

(36) The image processing device of any of (24) through (35) and (37) through (42), wherein the object is an image of furniture.

(37) The image processing device of any of (24) through (36) and (38) through (42), further including:

a purchase processing unit that performs a purchase process to purchase the furniture that is placed in the background image by the object placement unit.

(38) The image processing device of any of (24) through (37) and (39) through (42), further including

a transmission unit that transmits multiview image data as the data of a multiview image and the depth data of the multiview image, the multiview image being formed with images having different viewpoints from one another and used for generating the background image.

(39) The image processing device of any of (24) through (38) and (40) through (42), further including:

a combined image data generation unit that generates the image data of the background image having the object placed therein by the object placement unit,

wherein the transmission unit further transmits the combined image data generated by the combined image data generation unit.

(40) The image processing device of any of (24) through (39), (41), and (42), further including:

an application parameter generation unit that generates application parameters that are

parameters related to combining of the background image and the object,
wherein the transmission unit further transmits the application parameters generated by the application parameter generation unit.

(41) The image processing device of any of (24) through (40) and (42), further including:
a metadata generation unit that generates metadata about the multiview image,
wherein the transmission unit further transmits the metadata generated by the metadata generation unit.

(42) The image processing device of any of (24) through (41), wherein the metadata includes the base-line length information.

(43) An image processing method including:
setting the orientation and the size of an object in a position in which the object is to be placed in a background image, the orientation and the size being set based on depth data, base-line length information, and the three-dimensional modeling data of the object, the depth data indicating the distance to a subject in the background image, the base-line length information being information indicating a reference length in the background image; and
placing the object having the set orientation and the set size in the designated position in the background image.

Reference Signs List

[0346] 100 Multiview-image using service platform
200 Multiview-image using service providing system
201 Terminal device
202 Server
221 CPU
236 Imaging unit
251 CPU
281 Imaging control unit
282 Metadata generation unit
283 Encoding unit
284 Transmission control unit
291 User management unit
292 Acquisition control unit
293 Depth detection unit
294 File generation unit
295 Data management unit
321 Multiview image file

331 Multiview image encoded data
332 Depth data
333 Metadata
401 Terminal device
402 Application providing server
411 CPU
441 Application purchase processing unit
451 User management unit
452 Application sales processing unit
453 Data management unit
461 Application provision processing unit
511 User instruction reception processing unit
512 Display control unit
513 Transmission control unit
521 User management unit
522 Application selection processing unit
523 Image selection processing unit
524 Lens selection processing unit
525 User designated parameter setting unit
526 Virtual lens processing unit
527 Data management unit
601 Furniture sales server
651 User instruction reception processing unit
652 Display control unit
653 Imaging control unit
654 Metadata generation unit
655 Depth detection unit
656 Virtual captured image generation unit
657 Furniture image placement processing unit
658 Purchase processing unit
659 File generation unit
660 Combined image data generation unit
661 Application parameter generation unit
662 Transmission control unit
671 User management unit
672 Application selection unit
673 Furniture data selection unit
674 Purchase processing unit

675 Acquisition control unit
676 Data management unit
681 Furniture data provision unit
682 Purchase processing unit

Claims

[Claim 1] An image processing apparatus, comprising:
circuitry configured to initiate a setting of an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object.

[Claim 2] The image processing apparatus according to claim 1,wherein the circuitry is further configured to initiate a changing of a condition of the object to a condition corresponding to a second position, based on a change of position at which the object is set from a first position to the second position.

[Claim 3] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a changing of a condition of the object from a condition associated with a first viewpoint to a condition associated with a second view point, based on a changing of a viewpoint of the background image from the first viewpoint to the second viewpoint.

[Claim 4] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a changing of a condition of the object from a condition associated with a first viewing direction to a condition associated with a second viewing direction, based on a changing of a direction of a viewpoint of the background image from the first viewing direction to the second viewing direction.

[Claim 5] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a moving of the object, and repositioning of the object to have a condition of making contact with a plane of the background image.

[Claim 6] The image processing apparatus according to claim 5, wherein the condition of making contact with the plane is determined based on a distance between the object and the plane.

[Claim 7] The image processing apparatus according to claim 1, wherein a condition of the object is a condition associated with a position and an orientation of the object.

[Claim 8] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a simulation of a lighting in the background image based on light source parameters and the depth data,

the light source parameters being parameters related to a light source.

[Claim 9] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate an identification of a portion that satisfies line-of-flow conditions in the background image having the object placed therein, and initiates an emphasizing of the identified portion.

[Claim 10] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a setting of an image of a person within the background image, in accordance with a modeling condition associated with a position at which the image of the person is set within the background image having the object placed therein, and based on the depth data, the base-line length information, and modeling data of the image of the person.

[Claim 11] The image processing apparatus according to claim 1, wherein the object is selected from among one or more candidate objects, in accordance with a modeling condition of the selected object associated with a position at which the selected object is set in the background image, and based on the depth data, the base-line length information, and the modeling data of the selected object.

[Claim 12] The image processing apparatus according to claim 11, wherein the one or more candidate objects are objects that can be placed within the background image.

[Claim 13] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a control of a capturing of an image of a subject, initiate an obtaining of the captured image as the background image, and initiate a generation of depth data of the captured image.

[Claim 14] The image processing apparatus according to claim 13, wherein
the captured image is a multiview image formed with a plurality of images having different viewpoints from one another, and
the circuitry is further configured to initiate a generation of depth data of the multiview image, and to initiate a generation of a virtual captured image as the background image based on the multiview image and the depth data, the virtual captured image being obtained by imaging a subject of the multiview image.

[Claim 15] The image processing apparatus according to claim 1, wherein the object is an image of furniture.

[Claim 16] The image processing apparatus according to claim 15, wherein the

circuitry is further configured to initiate a performing of a purchase process to purchase the furniture that is placed within the background image.

[Claim 17] The image processing apparatus according to claim 1, wherein the circuitry is further configured to initiate a transmission of multiview image data as data of a multiview image and depth data of the multiview image, the multiview image being formed with a plurality of images having different viewpoints from one another and used for generating the background image.

[Claim 18] The image processing apparatus according to claim 17, wherein the circuitry is further configured to initiate a generation of image data of the background image having the object set therein, and initiate a transmission of the generated image data.

[Claim 19] The image processing apparatus according to claim 17, wherein the circuitry is further configured to initiate a generation of an application parameter that is a parameter related to a combining of the background image and the object, and initiate a transmission of the generated application parameter.

[Claim 20] The image processing apparatus according to claim 17, wherein the circuitry is further configured to initiate a generation of metadata about the multiview image, and initiate a transmission of the generated metadata.

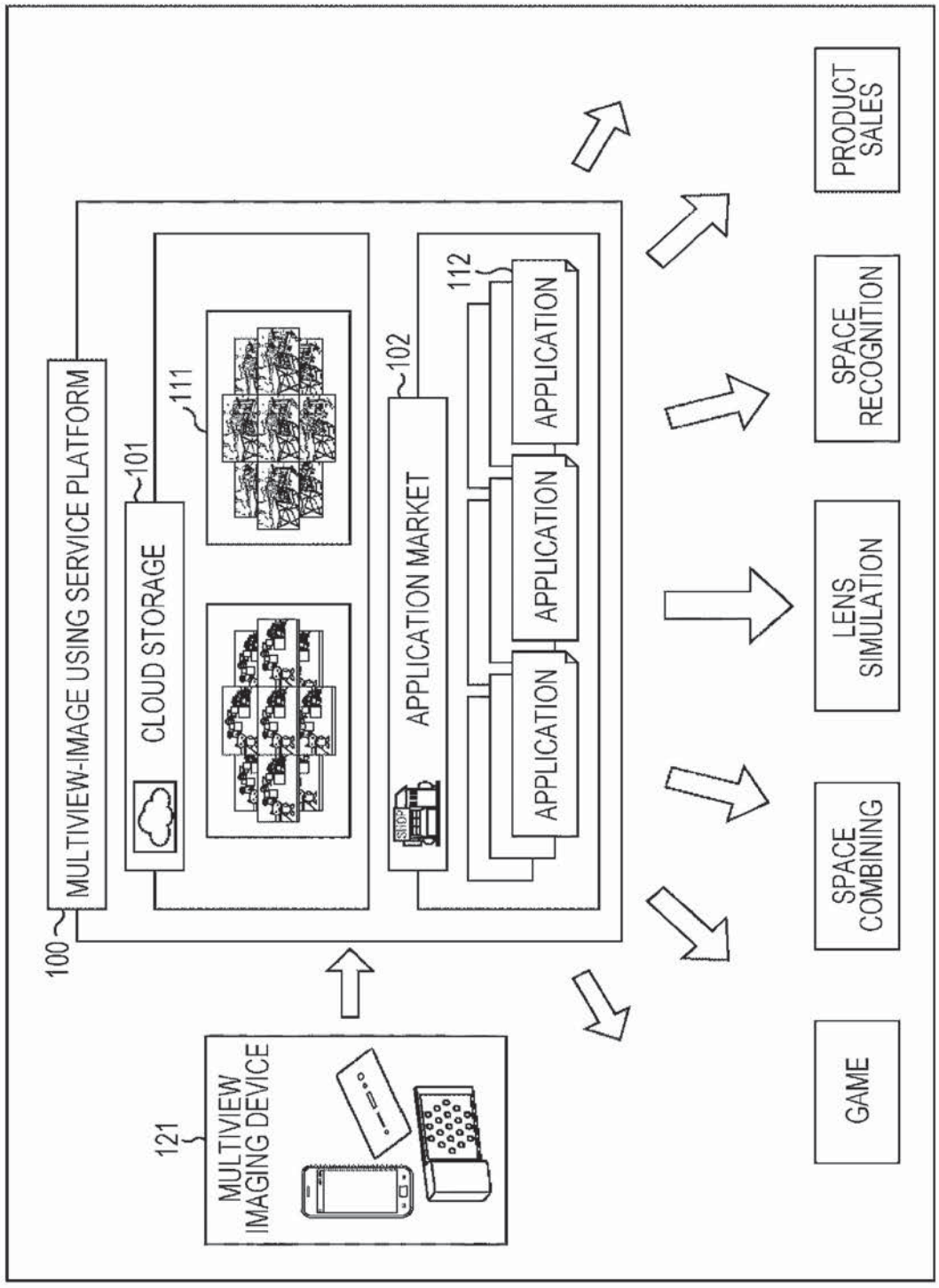
[Claim 21] The image processing apparatus according to claim 19, wherein the metadata includes the base-line length information.

[Claim 22] The image processing apparatus according to claim 1, wherein the depth data indicates a distance of depth direction in the background image, and the base-line length information indicates a reference length associated with the background image.

[Claim 23] An image processing method comprising:
setting an object for display within a background image in accordance with a modeling condition associated with a position at which the object is set, based on depth data and base-line length information associated with the background image and modeling data of the object; and
placing the set object to be displayed at the position within the background image.

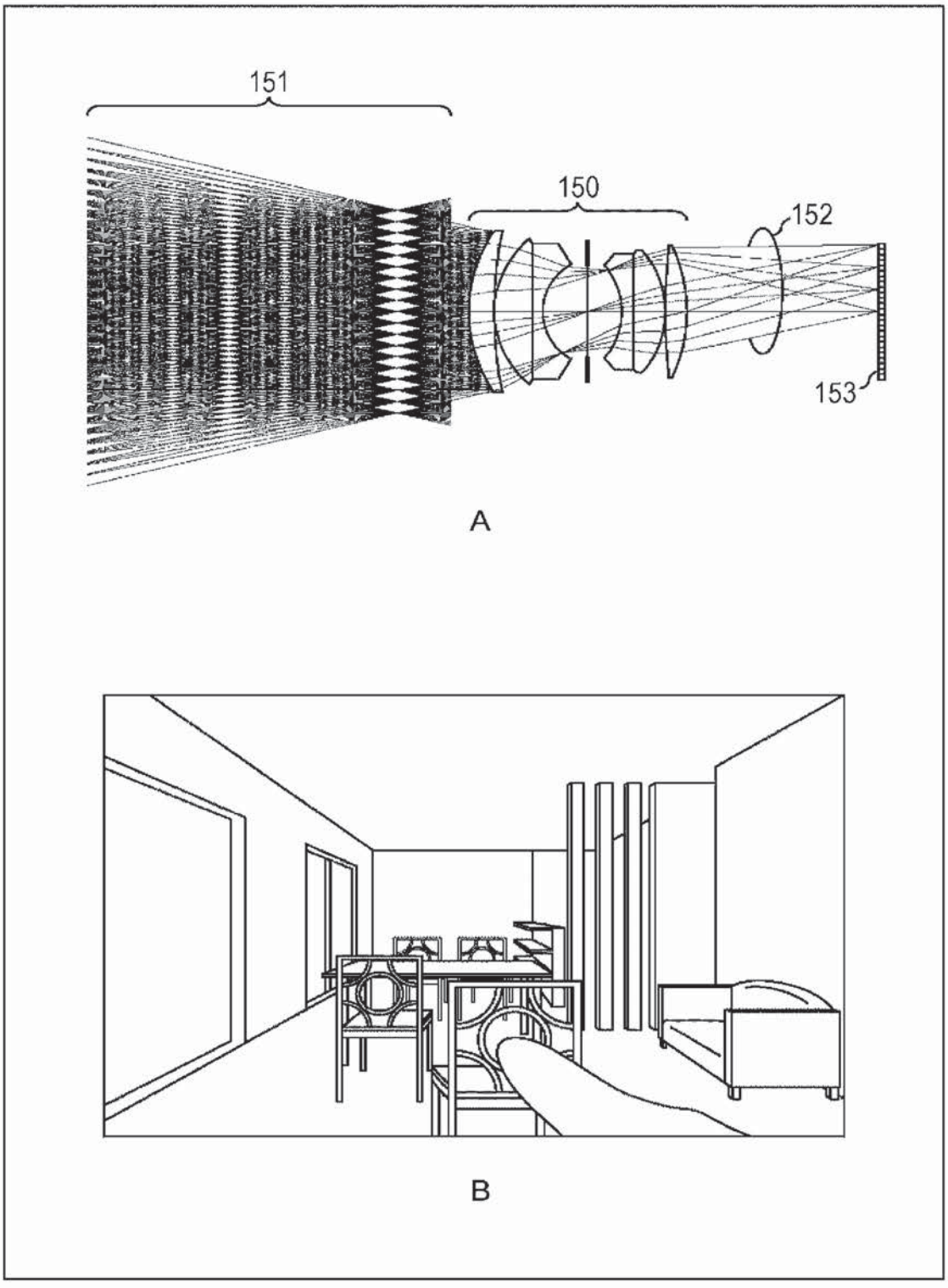
[Fig. 1]

FIG. 1


MULTIVIEW-IMAGE USING SERVICE PLATFORM
100
CLOUD STORAGE
101
111
APPLICATION MARKET
102
112
APPLICATION
APPLICATION
APPLICATION
SHOP
MULTIVIEW IMAGING DEVICE
121
GAME
SPACE COMBINING
LENS SIMULATION
SPACE RECOGNITION
PRODUCT SALES

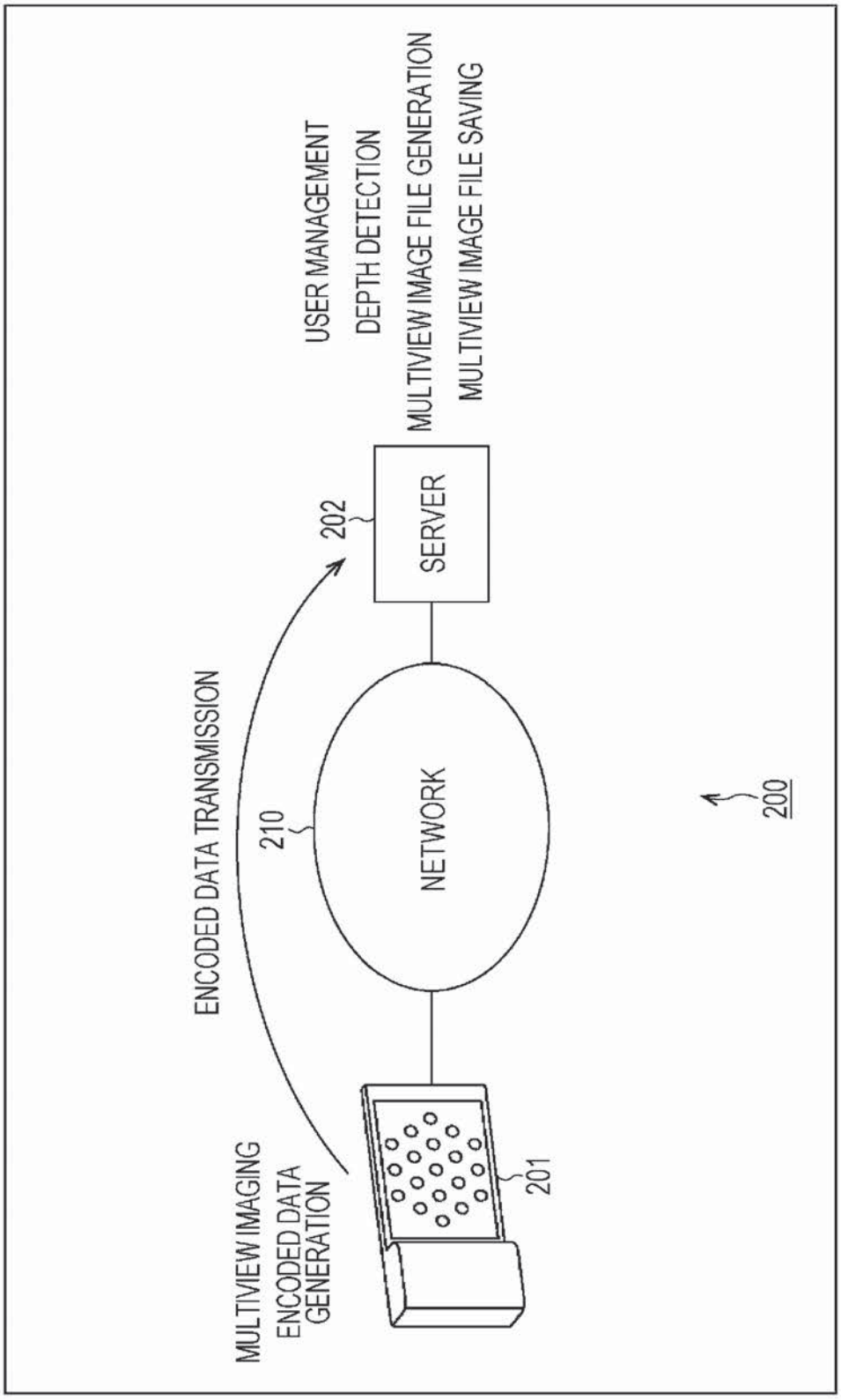
[Fig. 2]

FIG. 2



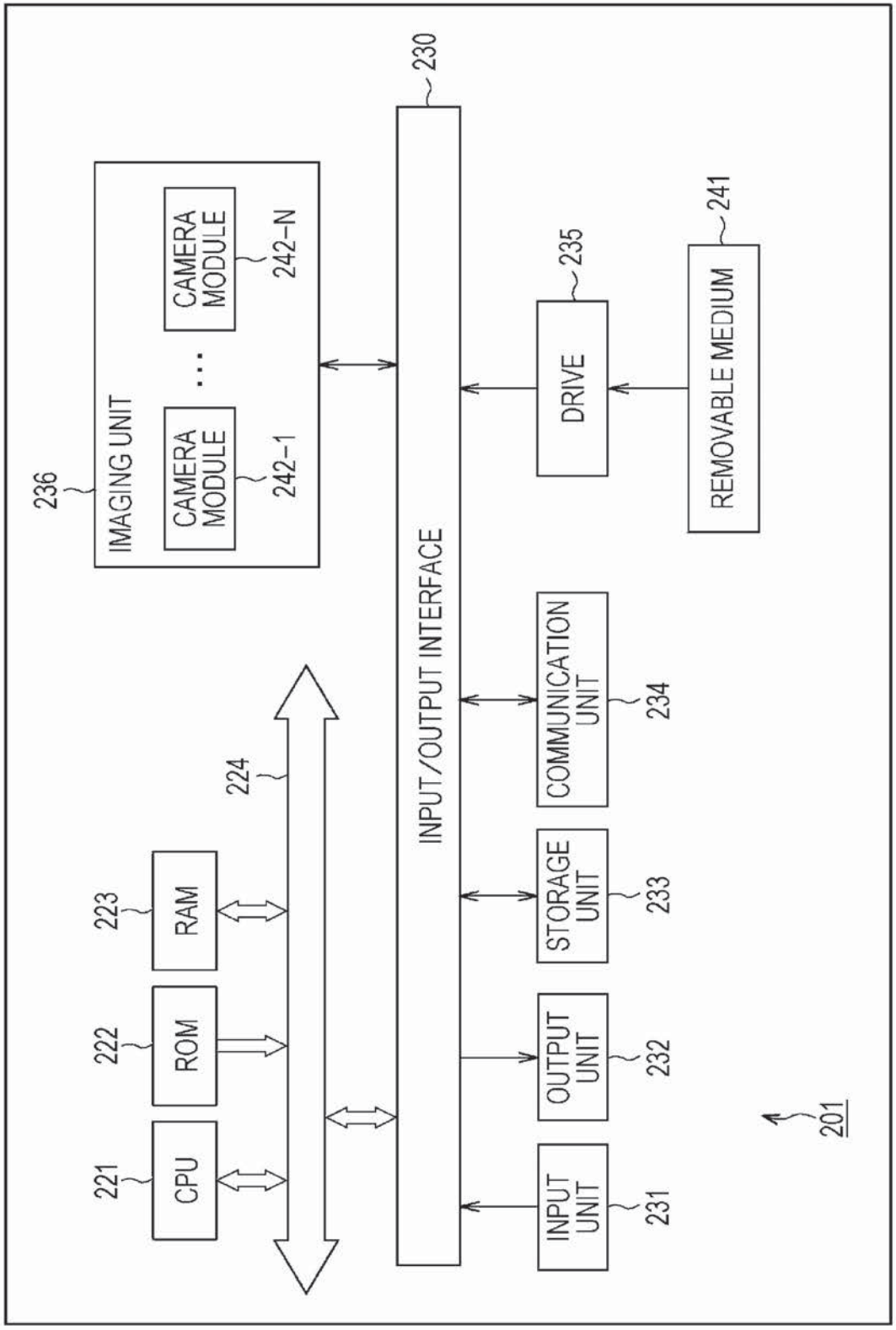
[Fig. 3]

FIG. 3


MULTIVIEW IMAGING
ENCODED DATA GENERATION
201
ENCODED DATA TRANSMISSION
210
NETWORK
202
SERVER
USER MANAGEMENT
DEPTH DETECTION
MULTIVIEW IMAGE FILE GENERATION
MULTIVIEW IMAGE FILE SAVING
200

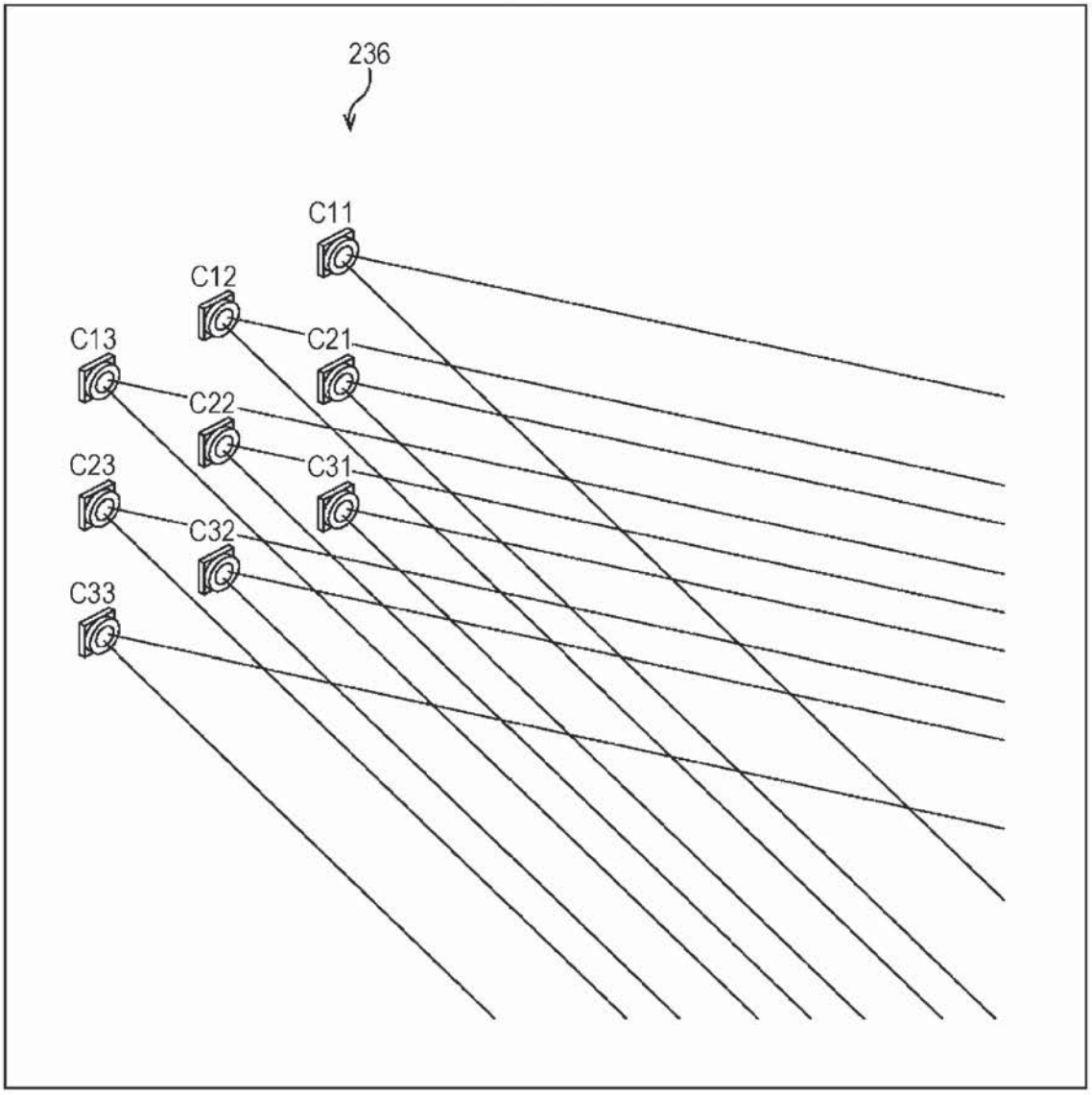
[Fig. 4]

FIG. 4


201
CPU
221
ROM
222
RAM
223
224
INPUT UNIT
231
OUTPUT UNIT
232
STORAGE UNIT
233
COMMUNICATION UNIT
234
INPUT/OUTPUT INTERFACE
230
DRIVE
235
REMOVABLE MEDIUM
241
IMAGING UNIT
236
CAMERA MODULE
242-1
CAMERA MODULE
242-N

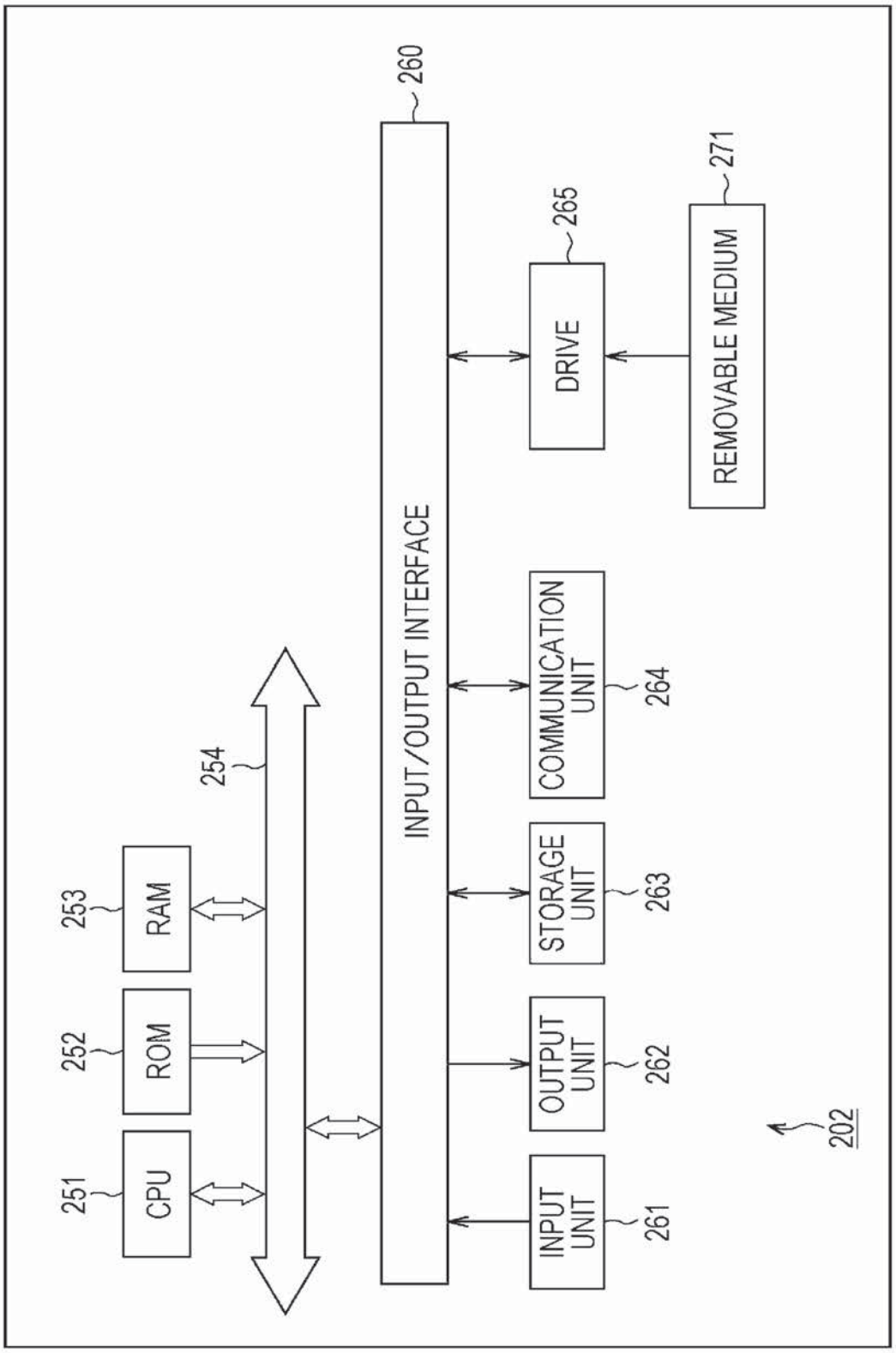
[Fig. 5]

FIG. 5



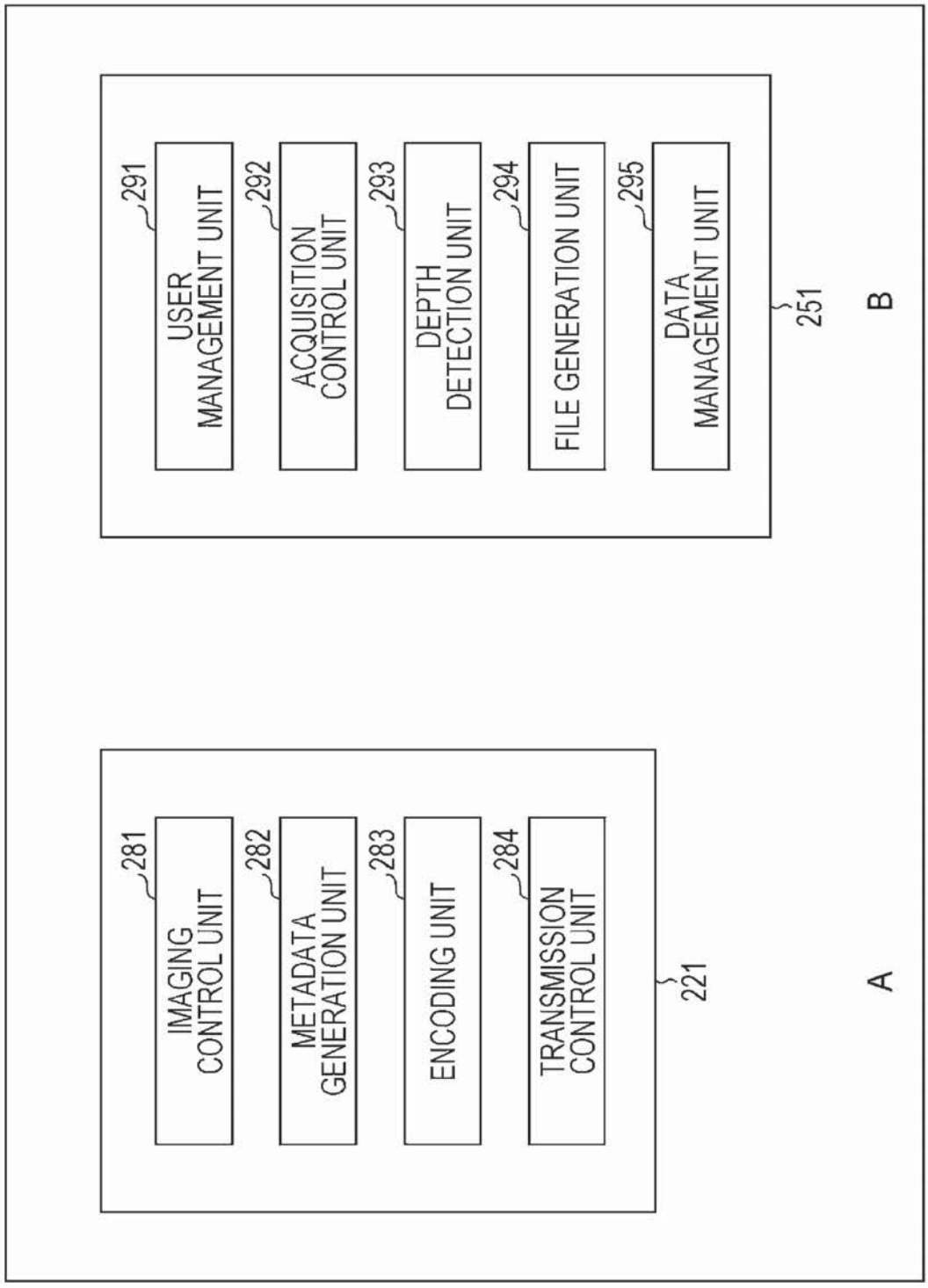
[Fig. 6]

FIG. 6


CPU
ROM
RAM
INPUT UNIT
OUTPUT UNIT
STORAGE UNIT
COMMUNICATION UNIT
DRIVE
REMOVABLE MEDIUM
INPUT/OUTPUT INTERFACE
251
252
253
254
260
261
262
263
264
265
271
202

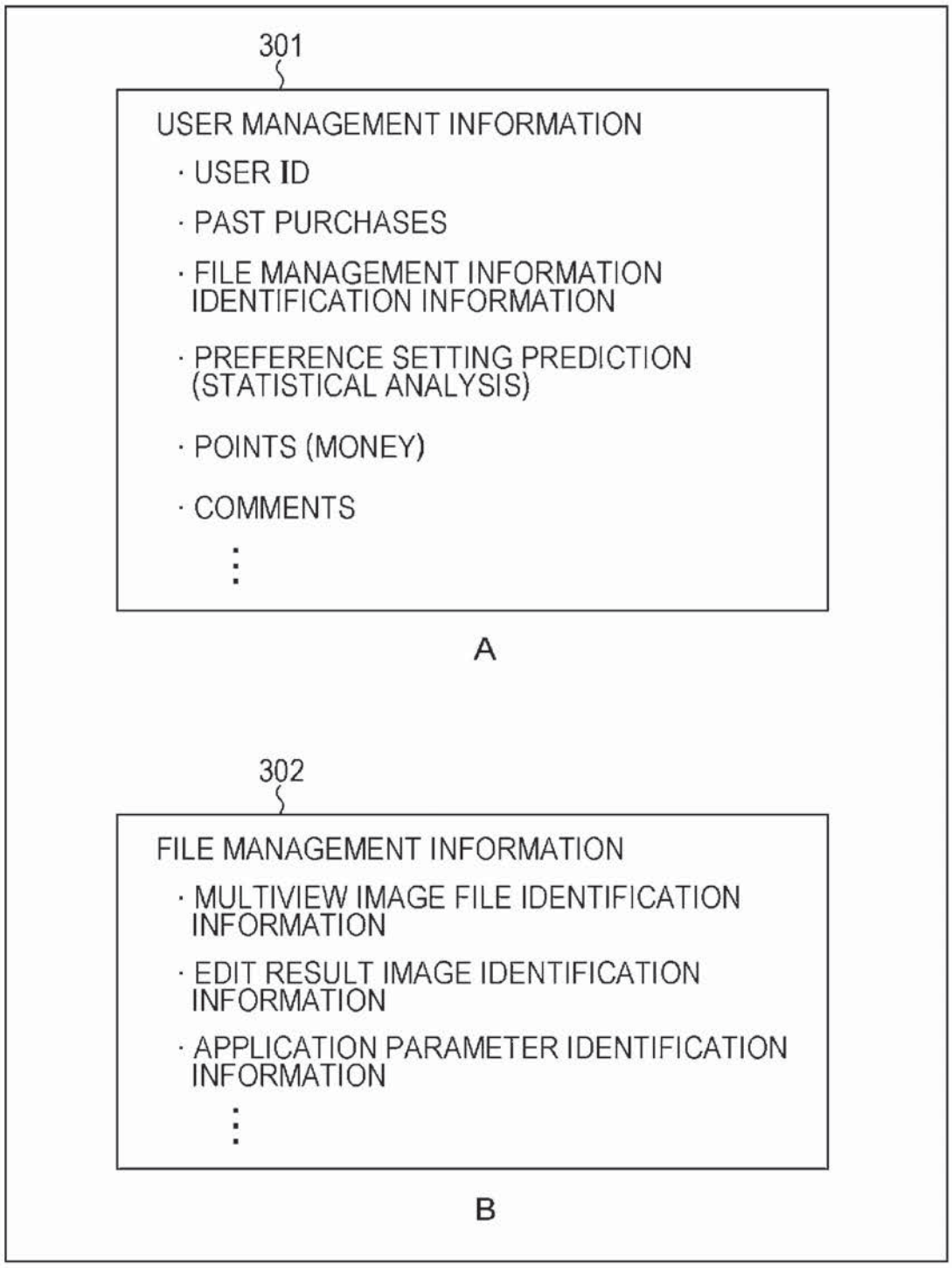
[Fig. 7]

FIG. 7


A
B
221
251
281
IMAGING CONTROL UNIT
282
METADATA GENERATION UNIT
283
ENCODING UNIT
284
TRANSMISSION CONTROL UNIT
291
USER MANAGEMENT UNIT
292
ACQUISITION CONTROL UNIT
293
DEPTH DETECTION UNIT
294
FILE GENERATION UNIT
295
DATA MANAGEMENT UNIT

[Fig. 8]

FIG. 8


301
USER MANAGEMENT INFORMATION
· USER ID
· PAST PURCHASES
· FILE MANAGEMENT INFORMATION IDENTIFICATION INFORMATION
· PREFERENCE SETTING PREDICTION (STATISTICAL ANALYSIS)
· POINTS (MONEY)
· COMMENTS
A
302
FILE MANAGEMENT INFORMATION
· MULTIVIEW IMAGE FILE IDENTIFICATION INFORMATION
· EDIT RESULT IMAGE IDENTIFICATION INFORMATION
· APPLICATION PARAMETER IDENTIFICATION INFORMATION
B

[Fig. 9]

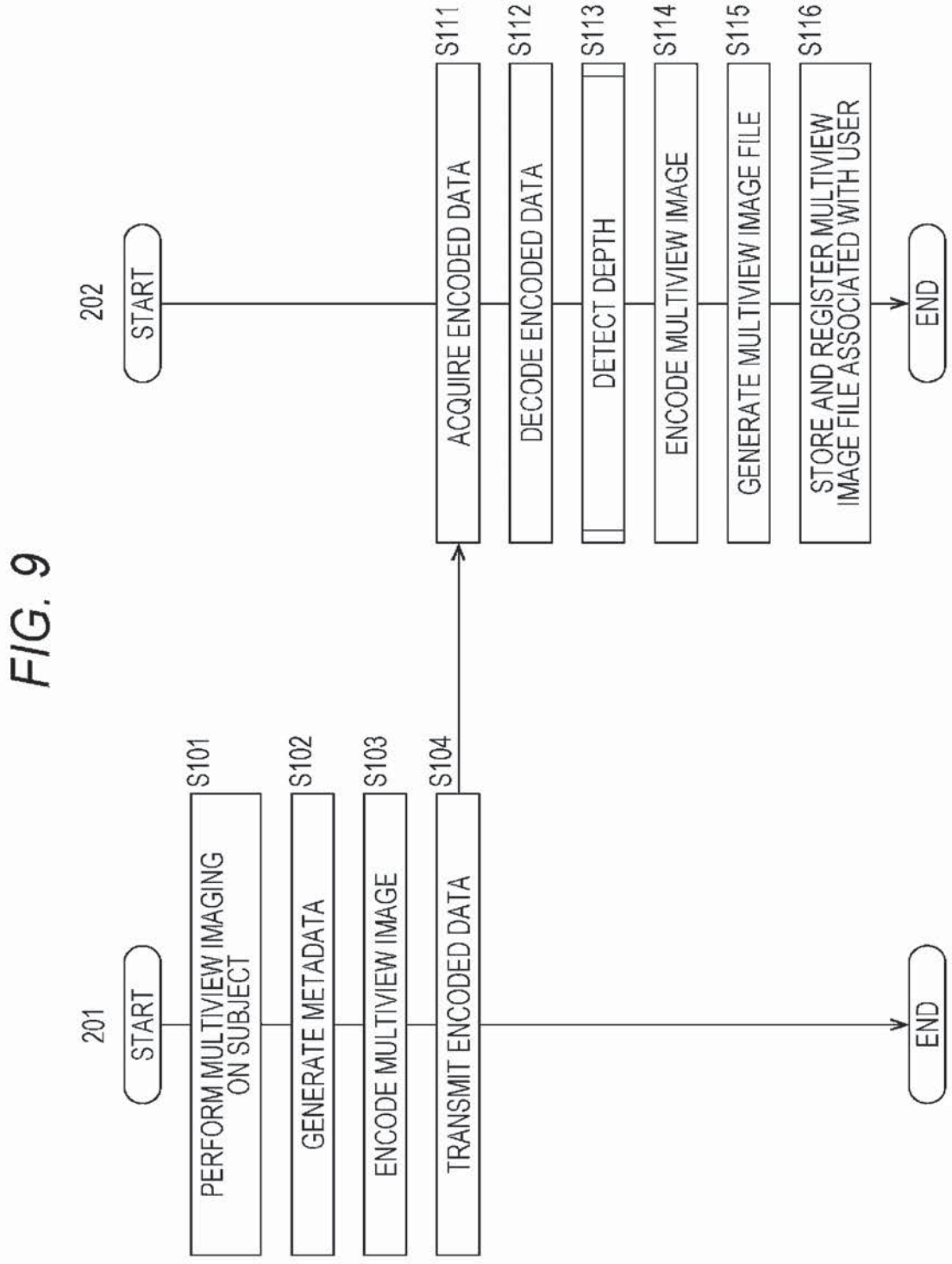
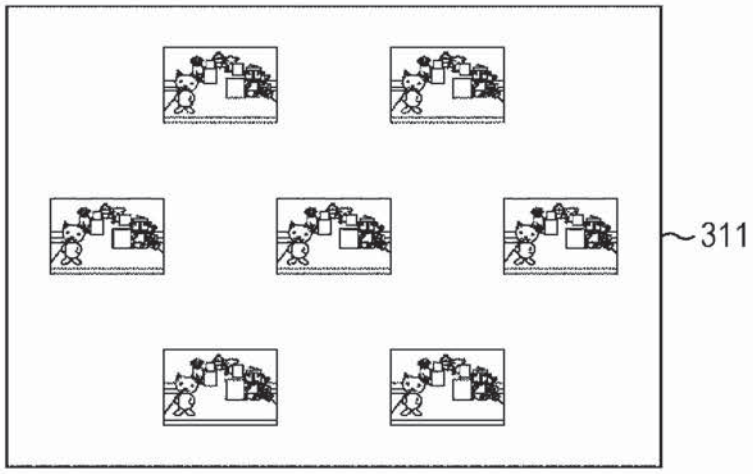

201
START
PERFORM MULTIVIEW IMAGING ON SUBJECT
S101
GENERATE METADATA
S102
ENCODE MULTIVIEW IMAGE
S103
TRANSMIT ENCODED DATA
S104
END
202
START
ACQUIRE ENCODED DATA
S111
DECODE ENCODED DATA
S112
DETECT DEPTH
S113
ENCODE MULTIVIEW IMAGE
S114
GENERATE MULTIVIEW IMAGE FILE
S115
STORE AND REGISTER MULTIVIEW IMAGE FILE ASSOCIATED WITH USER
S116
END

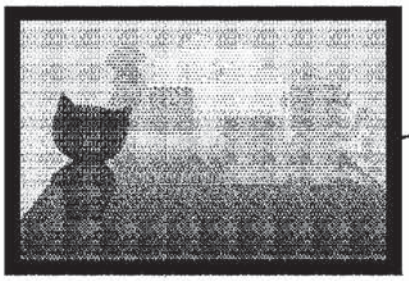
FIG. 9

[Fig. 10]

FIG. 10



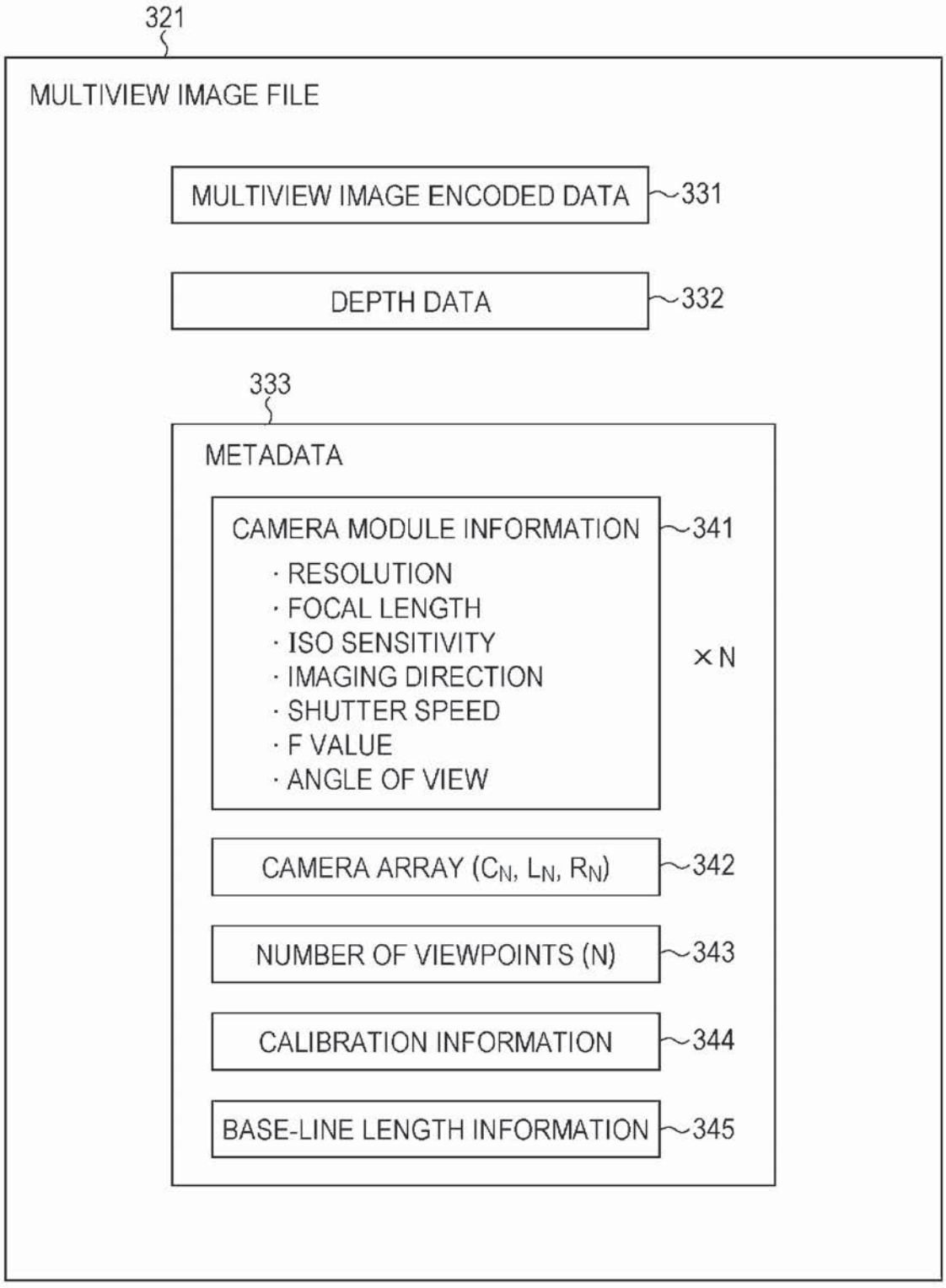
A



B

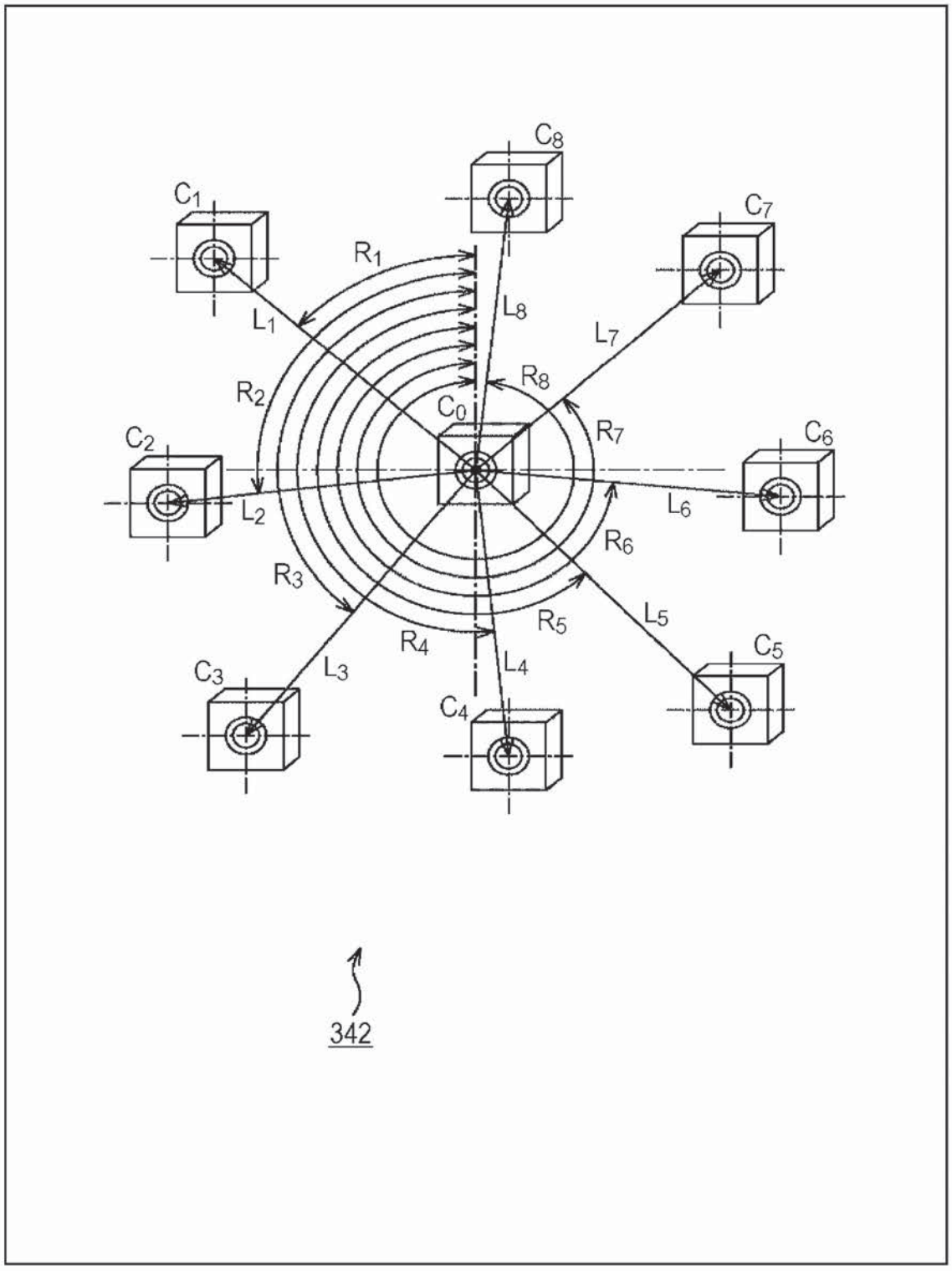
[Fig. 11]

FIG. 11


321
MULTIVIEW IMAGE FILE
MULTIVIEW IMAGE ENCODED DATA
331
DEPTH DATA
332
333
METADATA
CAMERA MODULE INFORMATION
341
· RESOLUTION
· FOCAL LENGTH
· ISO SENSITIVITY
· IMAGING DIRECTION
· SHUTTER SPEED
· F VALUE
· ANGLE OF VIEW
× N
CAMERA ARRAY (CN, LN, RN)
342
NUMBER OF VIEWPOINTS (N)
343
CALIBRATION INFORMATION
344
BASE-LINE LENGTH INFORMATION
345

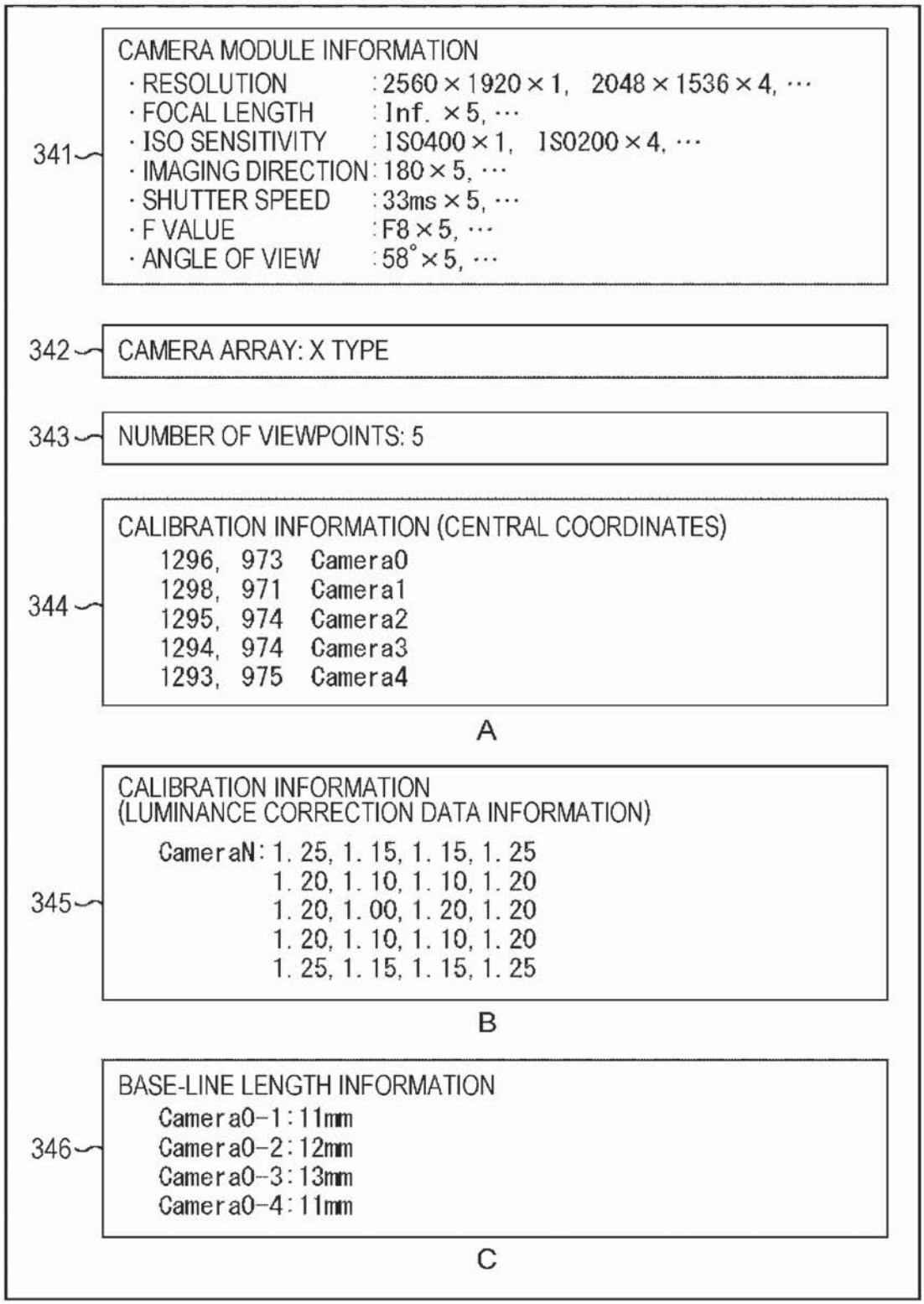
[Fig. 12]

FIG. 12


C8
C1
C7
R1
L1
L8
L7
R2
R8
C0
R7
C2
C6
L2
L6
R6
R3
R5
L5
R4
C5
C3
L3
L4
C4
342

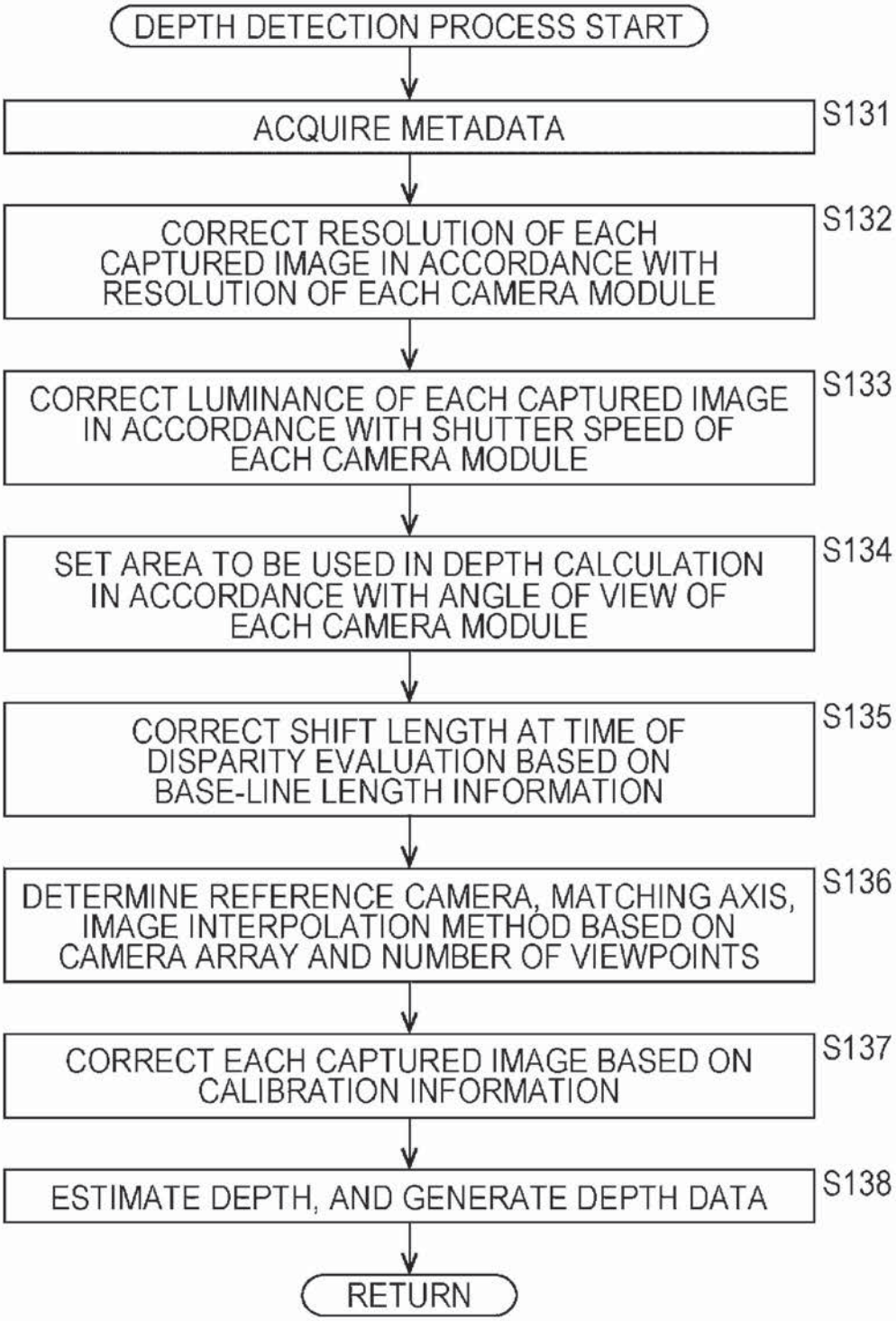
[Fig. 13]

FIG. 13


CAMERA MODULE INFORMATION
· RESOLUTION : 2560 × 1920 × 1, 2048 × 1536 × 4, ···
· FOCAL LENGTH : Inf. × 5, ···
· ISO SENSITIVITY : ISO400 × 1, ISO200 × 4, ···
· IMAGING DIRECTION : 180 × 5, ···
· SHUTTER SPEED : 33ms × 5, ···
· F VALUE : F8 × 5, ···
· ANGLE OF VIEW : 58° × 5, ···
341
CAMERA ARRAY: X TYPE
342
NUMBER OF VIEWPOINTS: 5
343
CALIBRATION INFORMATION (CENTRAL COORDINATES)
1296, 973 Camera0
1298, 971 Camera1
1295, 974 Camera2
1294, 974 Camera3
1293, 975 Camera4
344
A
CALIBRATION INFORMATION
(LUMINANCE CORRECTION DATA INFORMATION)
CameraN: 1.25, 1.15, 1.15, 1.25
1.20, 1.10, 1.10, 1.20
1.20, 1.00, 1.20, 1.20
1.20, 1.10, 1.10, 1.20
1.25, 1.15, 1.15, 1.25
345
B
BASE-LINE LENGTH INFORMATION
Camera0-1 : 11mm
Camera0-2 : 12mm
Camera0-3 : 13mm
Camera0-4 : 11mm
346
C

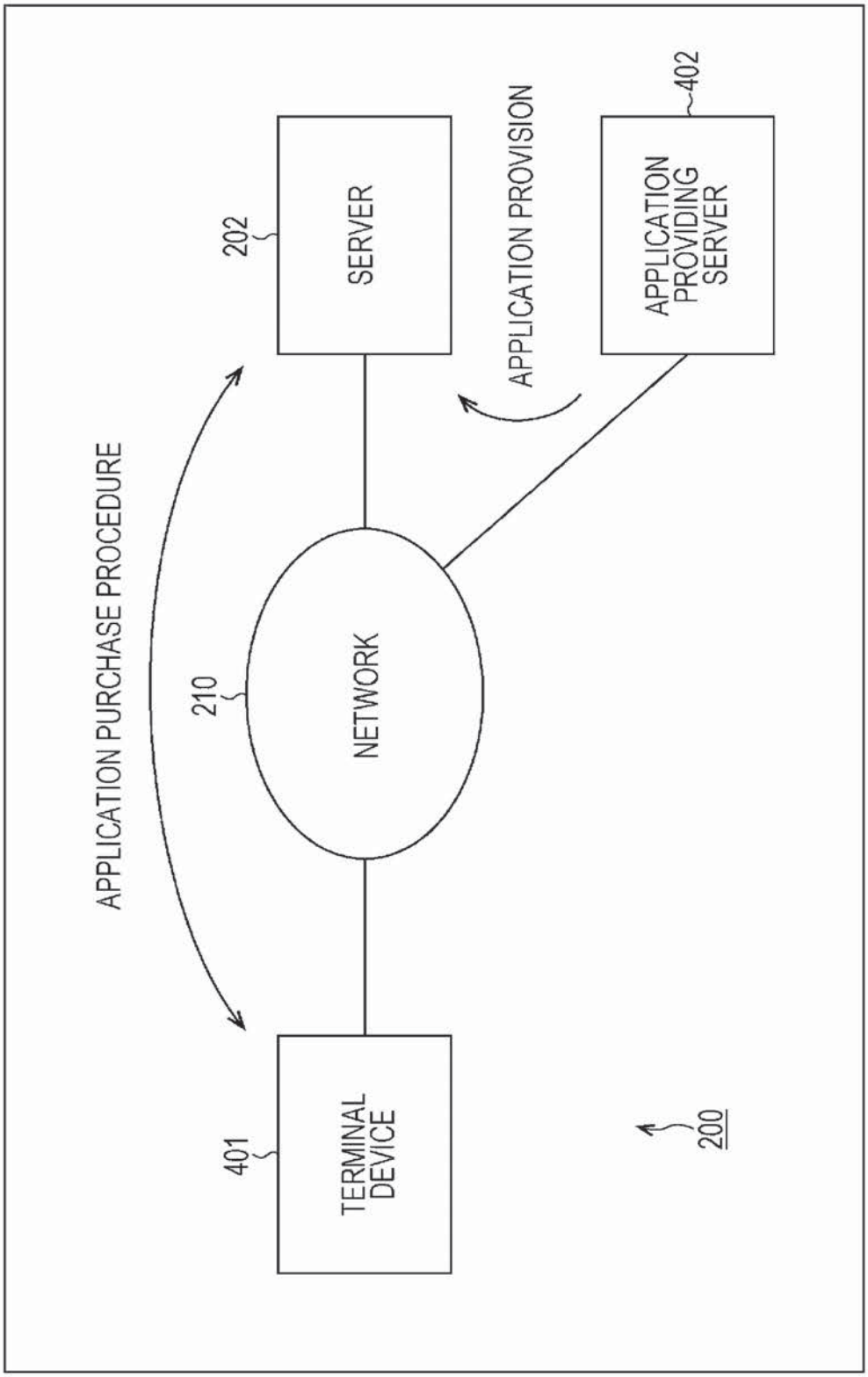
[Fig. 14]

FIG. 14


DEPTH DETECTION PROCESS START
ACQUIRE METADATA
S131
CORRECT RESOLUTION OF EACH CAPTURED IMAGE IN ACCORDANCE WITH RESOLUTION OF EACH CAMERA MODULE
S132
CORRECT LUMINANCE OF EACH CAPTURED IMAGE IN ACCORDANCE WITH SHUTTER SPEED OF EACH CAMERA MODULE
S133
SET AREA TO BE USED IN DEPTH CALCULATION IN ACCORDANCE WITH ANGLE OF VIEW OF EACH CAMERA MODULE
S134
CORRECT SHIFT LENGTH AT TIME OF DISPARITY EVALUATION BASED ON BASE-LINE LENGTH INFORMATION
S135
DETERMINE REFERENCE CAMERA, MATCHING AXIS, IMAGE INTERPOLATION METHOD BASED ON CAMERA ARRAY AND NUMBER OF VIEWPOINTS
S136
CORRECT EACH CAPTURED IMAGE BASED ON CALIBRATION INFORMATION
S137
ESTIMATE DEPTH, AND GENERATE DEPTH DATA
S138
RETURN

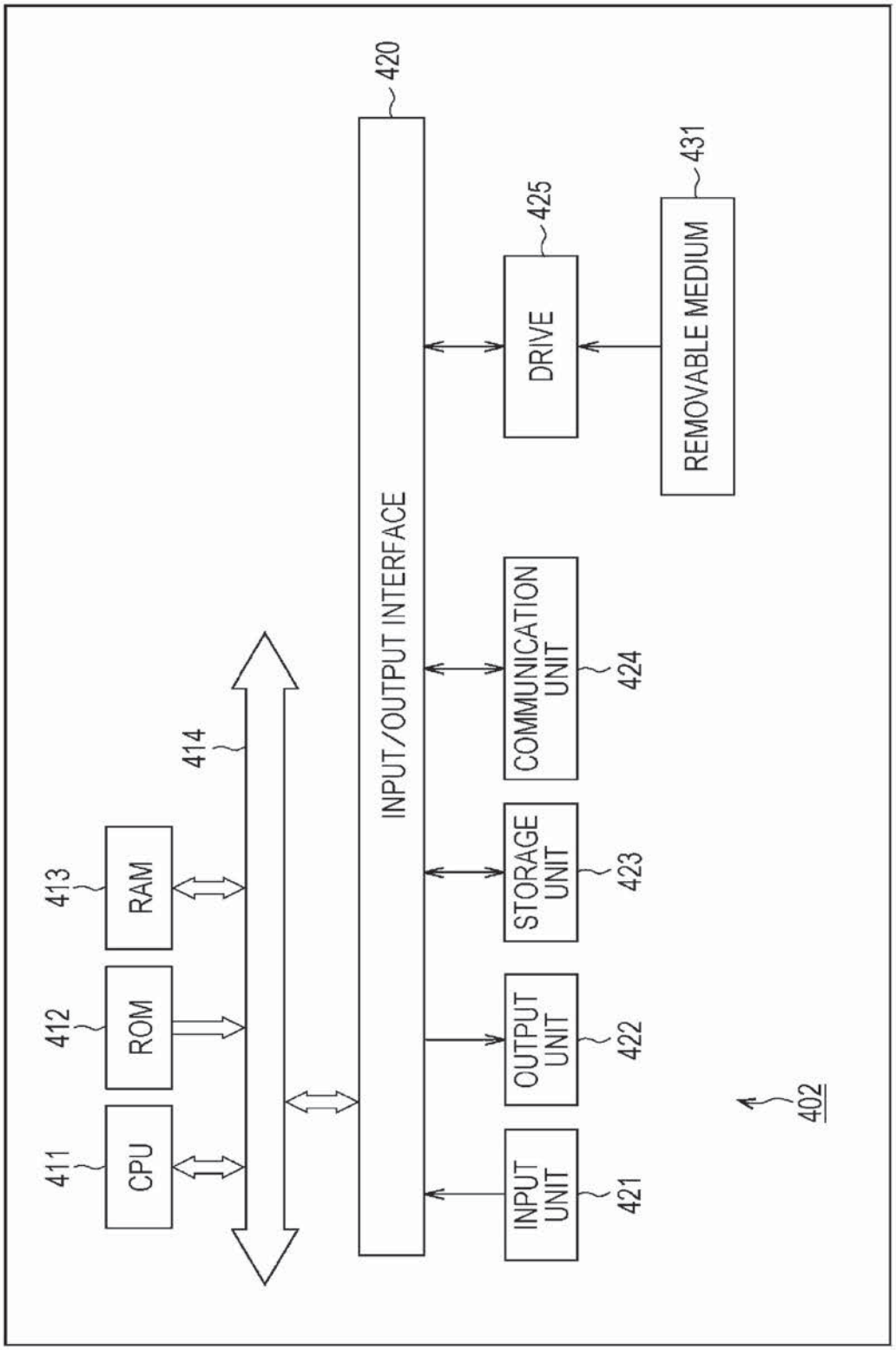
[Fig. 15]

FIG. 15


APPLICATION PURCHASE PROCEDURE
APPLICATION PROVISION
202
SERVER
402
APPLICATION PROVIDING SERVER
210
NETWORK
401
TERMINAL DEVICE
200

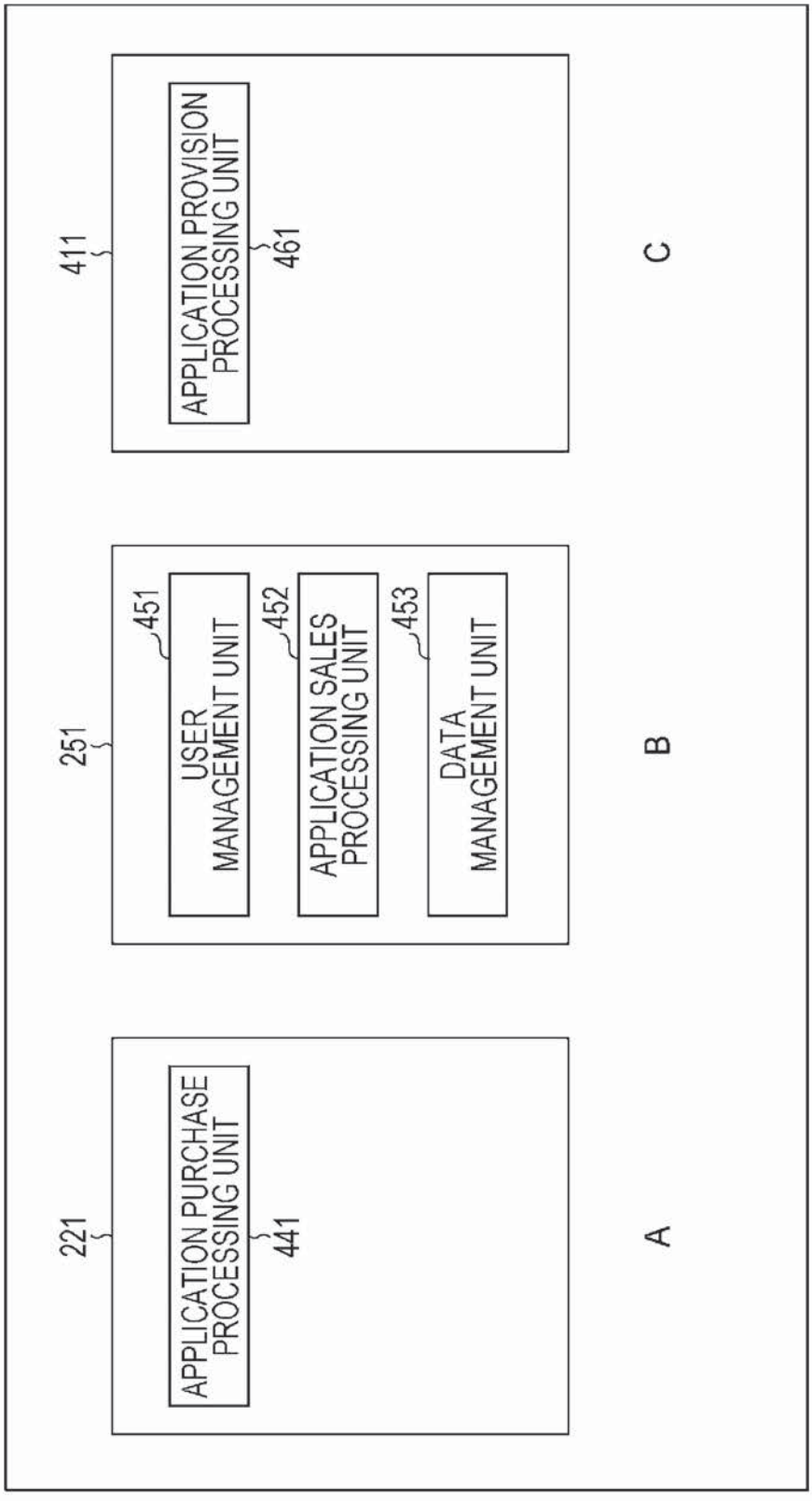
[Fig. 16]

FIG. 16


CPU
411
ROM
412
RAM
413
414
INPUT/OUTPUT INTERFACE
420
INPUT UNIT
421
OUTPUT UNIT
422
STORAGE UNIT
423
COMMUNICATION UNIT
424
DRIVE
425
REMOVABLE MEDIUM
431
402

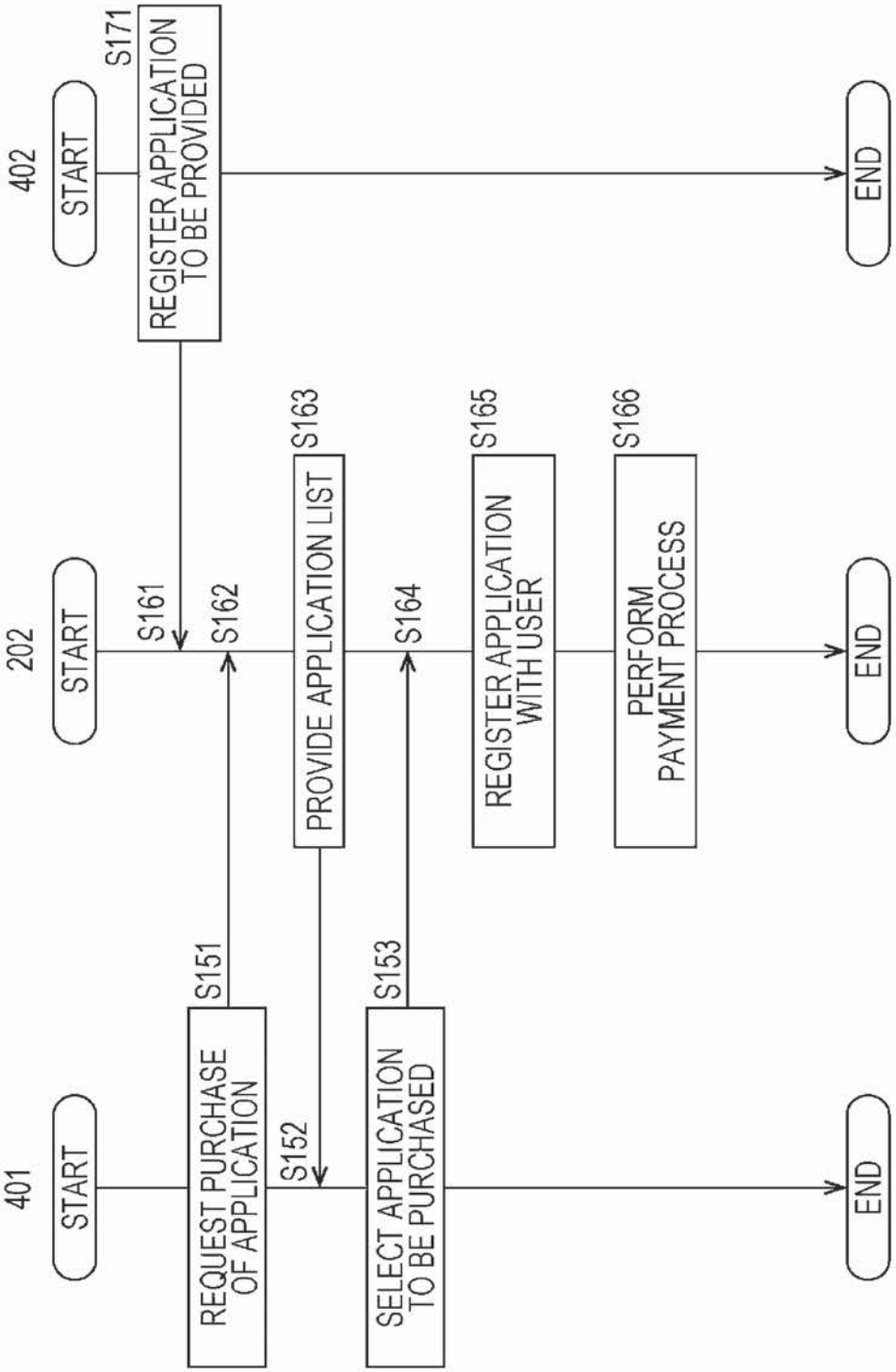
[Fig. 17]

FIG. 17


411
APPLICATION PROVISION PROCESSING UNIT
461
C
251
451
USER MANAGEMENT UNIT
452
APPLICATION SALES PROCESSING UNIT
453
DATA MANAGEMENT UNIT
B
221
APPLICATION PURCHASE PROCESSING UNIT
441
A

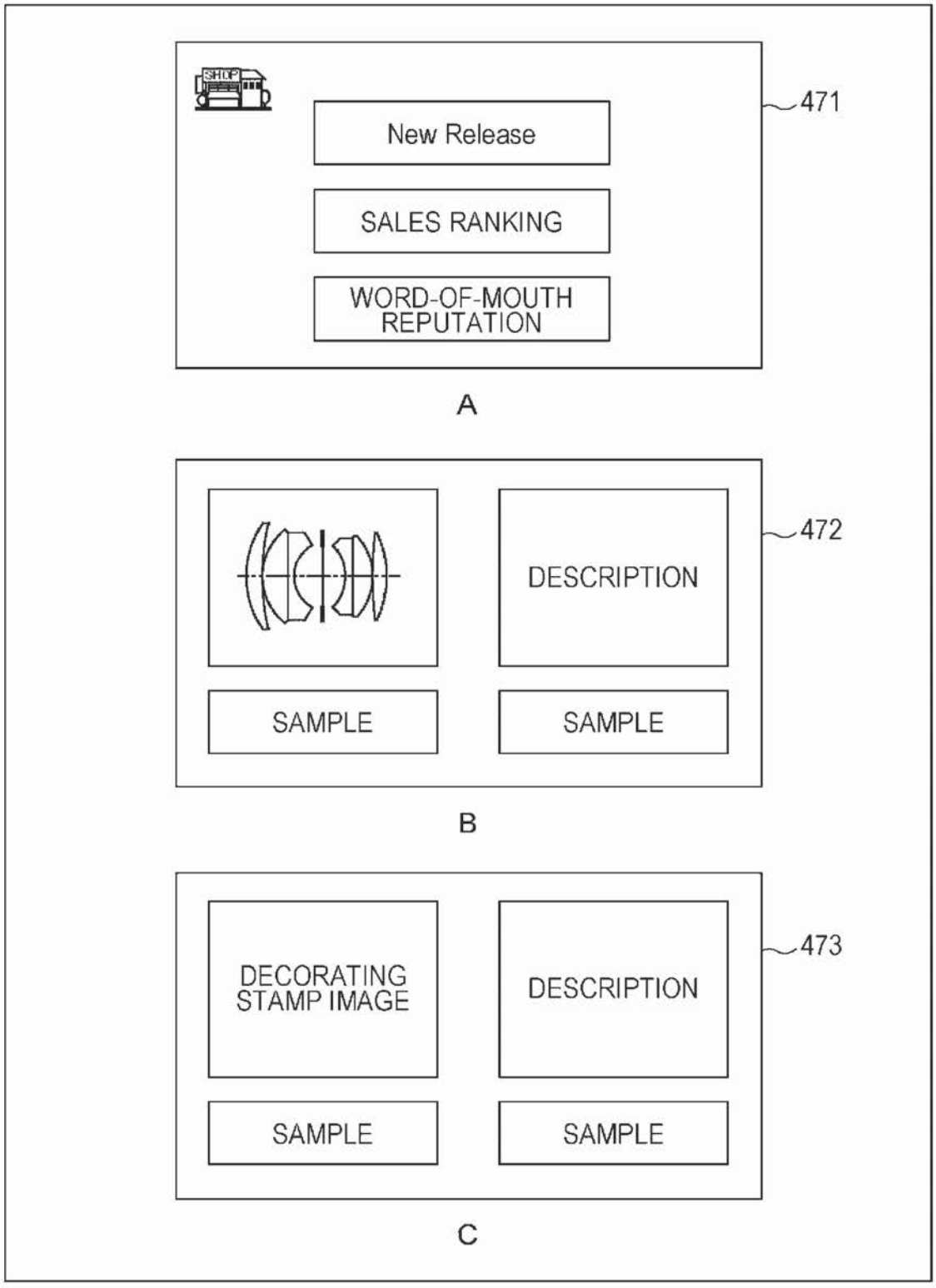
[Fig. 18]

FIG. 18


401
START
REQUEST PURCHASE OF APPLICATION
S151
S152
SELECT APPLICATION TO BE PURCHASED
S153
END
202
START
S161
S162
PROVIDE APPLICATION LIST
S163
S164
REGISTER APPLICATION WITH USER
S165
PERFORM PAYMENT PROCESS
S166
END
402
START
S171
REGISTER APPLICATION TO BE PROVIDED
END

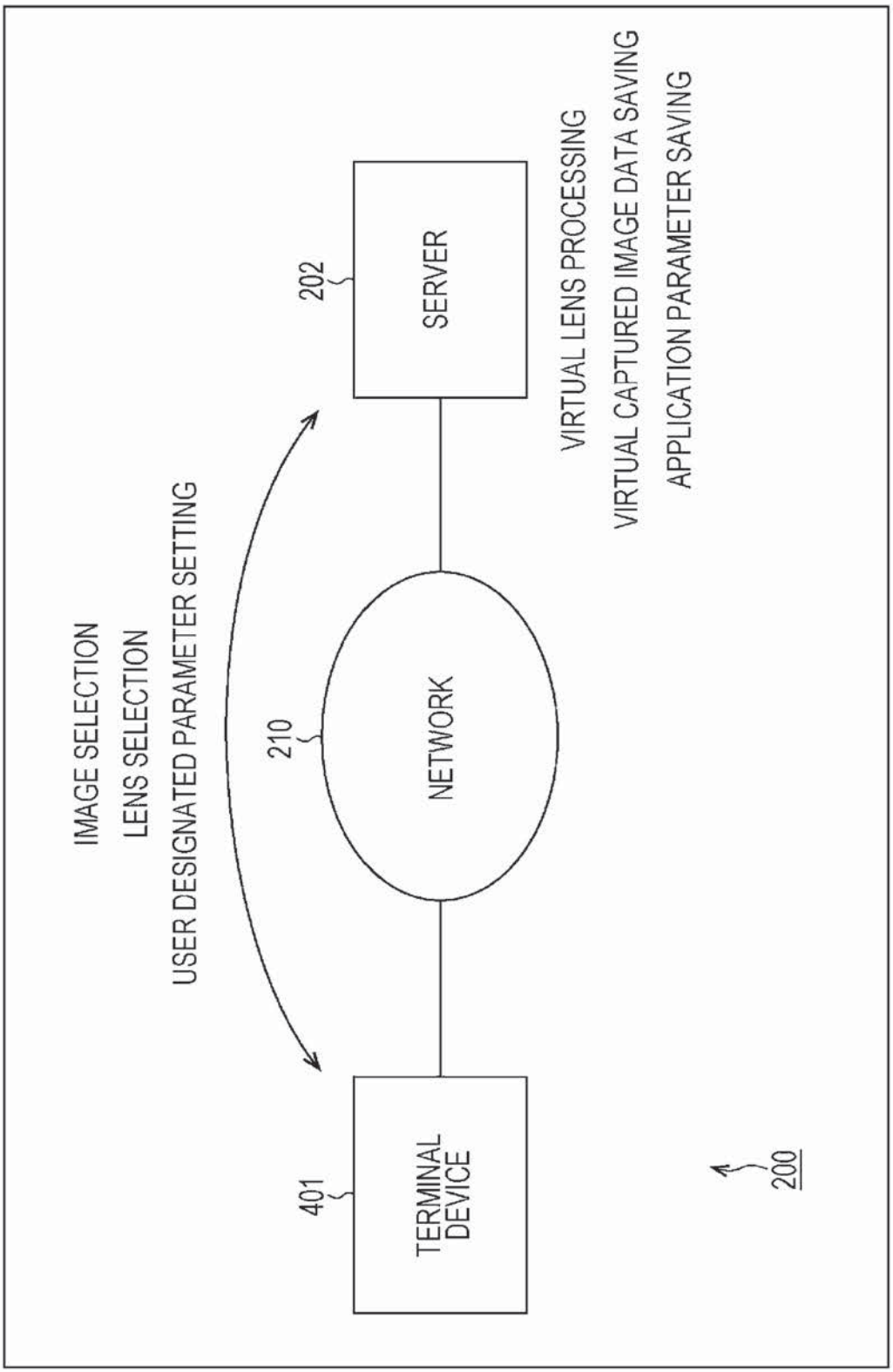
[Fig. 19]

FIG. 19


SHOP
New Release
SALES RANKING
WORD-OF-MOUTH REPUTATION
471
A
DESCRIPTION
SAMPLE
SAMPLE
472
B
DECORATING STAMP IMAGE
DESCRIPTION
SAMPLE
SAMPLE
473
C

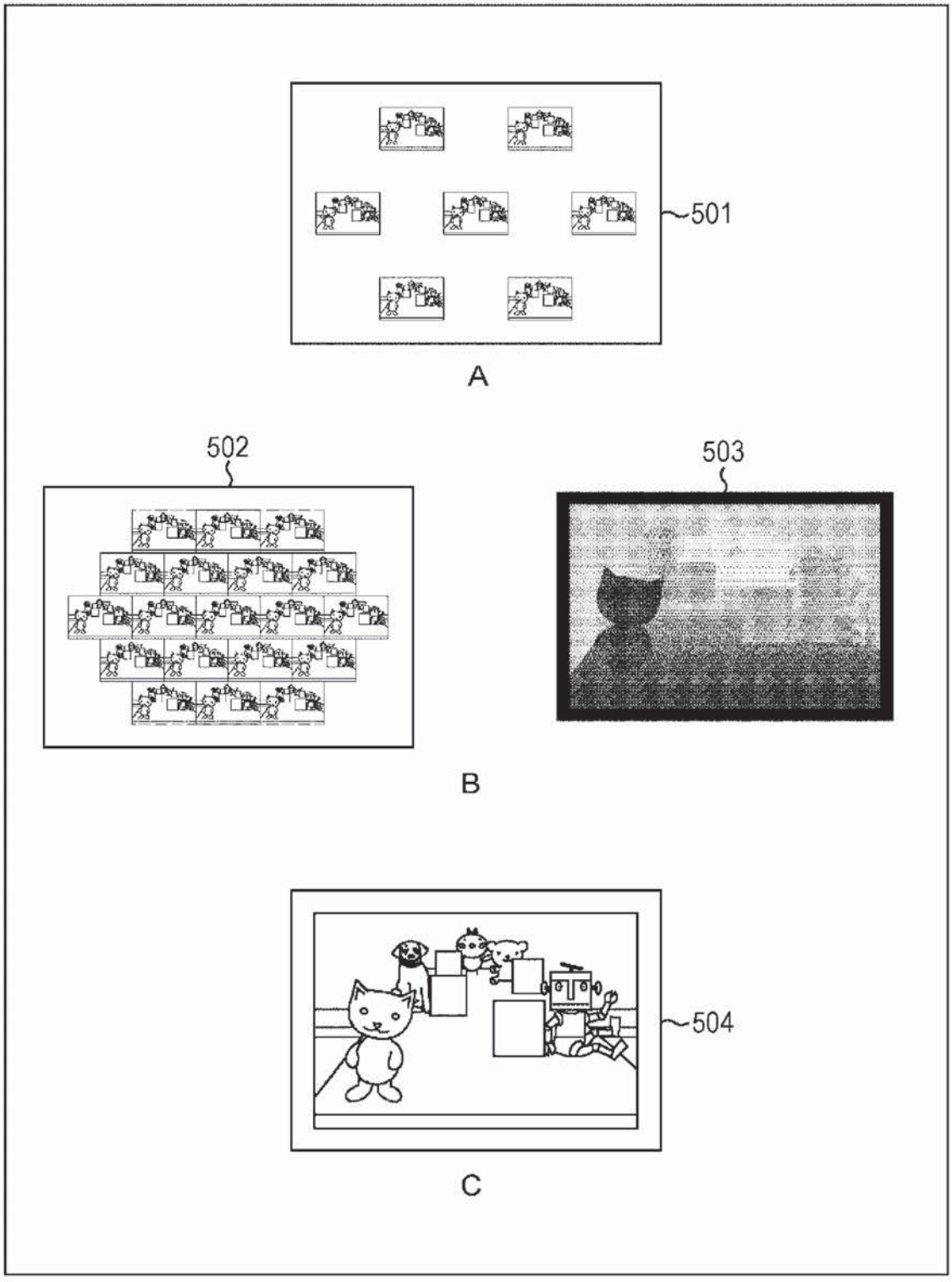
[Fig. 20]

FIG. 20


IMAGE SELECTION
LENS SELECTION
USER DESIGNATED PARAMETER SETTING
VIRTUAL LENS PROCESSING
VIRTUAL CAPTURED IMAGE DATA SAVING
APPLICATION PARAMETER SAVING
SERVER
202
NETWORK
210
TERMINAL DEVICE
401
200

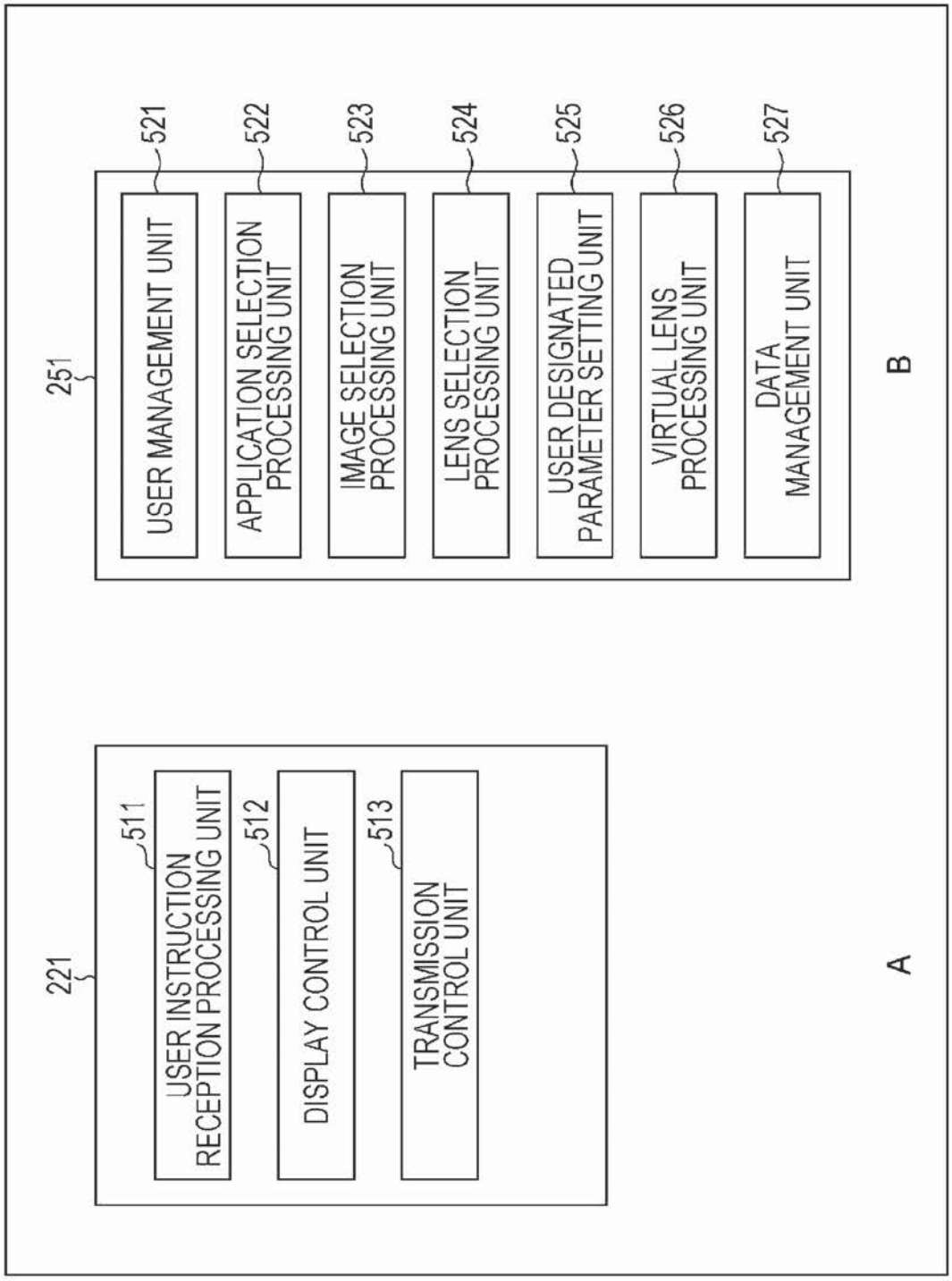
[Fig. 21]

FIG. 21



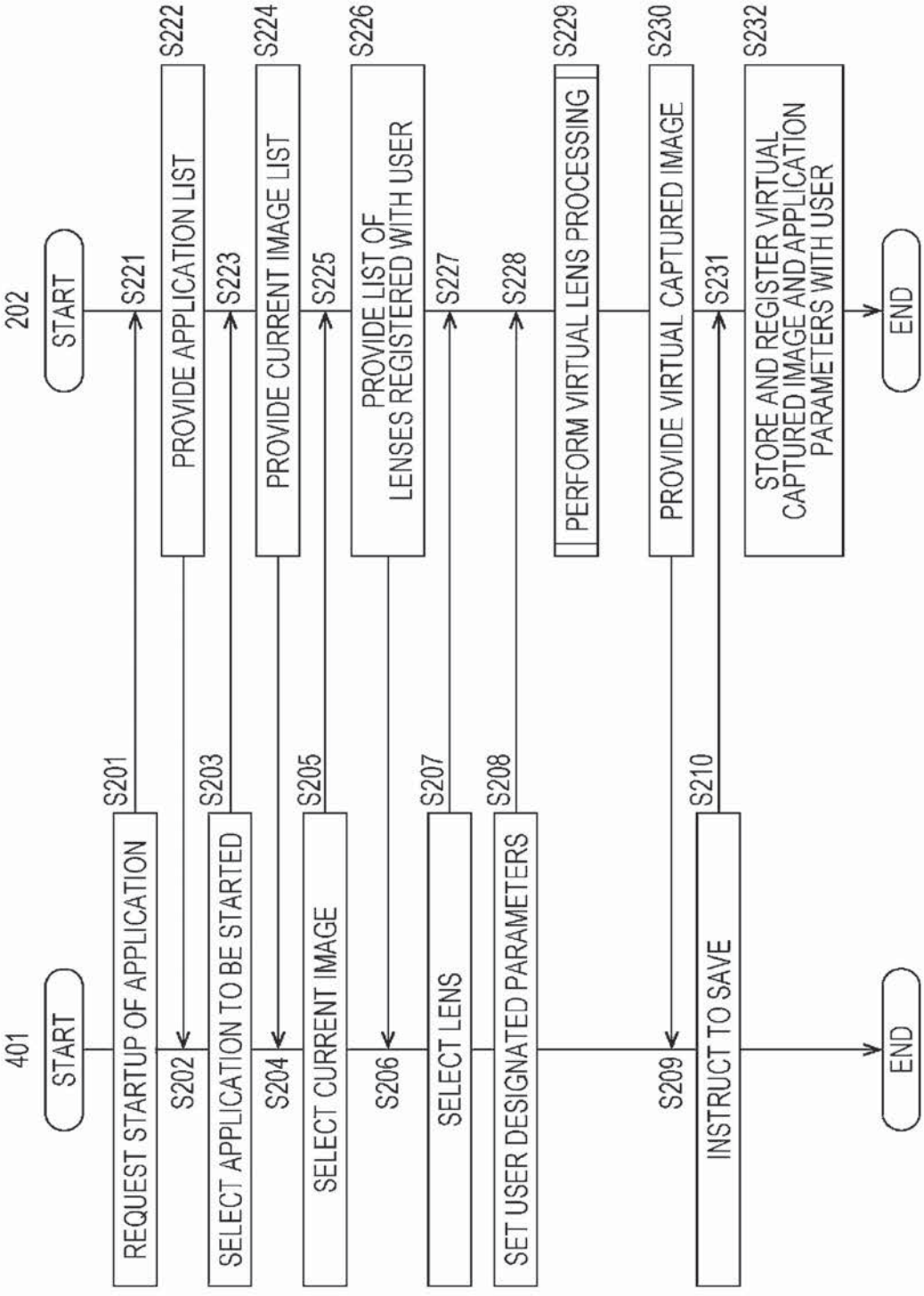
[Fig. 22]

FIG. 22


A
221
511
USER INSTRUCTION RECEPTION PROCESSING UNIT
512
DISPLAY CONTROL UNIT
513
TRANSMISSION CONTROL UNIT
B
251
521
USER MANAGEMENT UNIT
522
APPLICATION SELECTION PROCESSING UNIT
523
IMAGE SELECTION PROCESSING UNIT
524
LENS SELECTION PROCESSING UNIT
525
USER DESIGNATED PARAMETER SETTING UNIT
526
VIRTUAL LENS PROCESSING UNIT
527
DATA MANAGEMENT UNIT

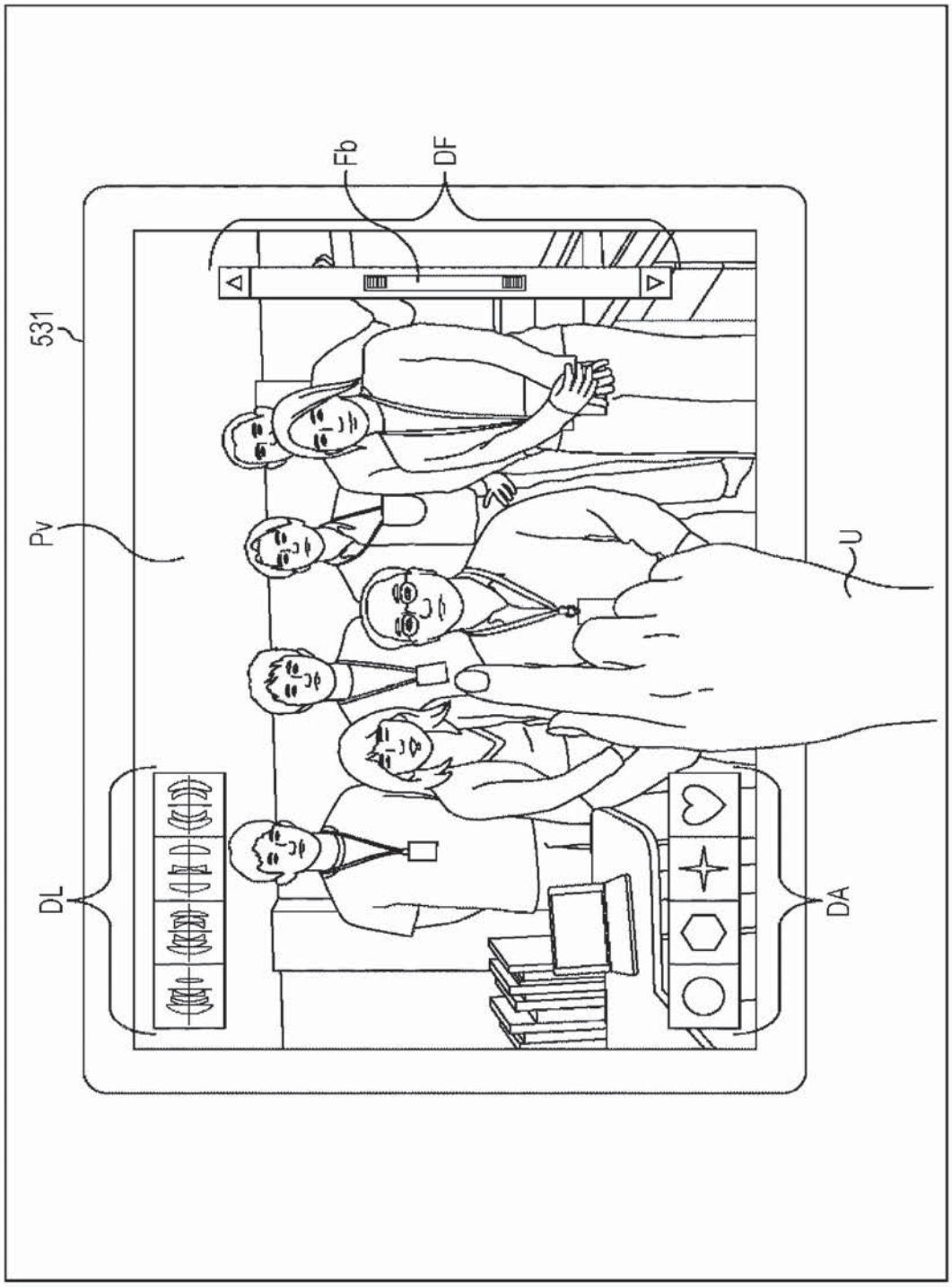
[Fig. 23]

FIG. 23


401
START
S201
REQUEST STARTUP OF APPLICATION
S202
202
START
S221
PROVIDE APPLICATION LIST
S222
S203
SELECT APPLICATION TO BE STARTED
S223
PROVIDE CURRENT IMAGE LIST
S224
S204
S205
SELECT CURRENT IMAGE
S225
PROVIDE LIST OF LENSES REGISTERED WITH USER
S226
S206
S207
SELECT LENS
S227
S208
SET USER DESIGNATED PARAMETERS
S228
PERFORM VIRTUAL LENS PROCESSING
S229
S209
S210
INSTRUCT TO SAVE
PROVIDE VIRTUAL CAPTURED IMAGE
S230
S231
STORE AND REGISTER VIRTUAL CAPTURED IMAGE AND APPLICATION PARAMETERS WITH USER
S232
END
END

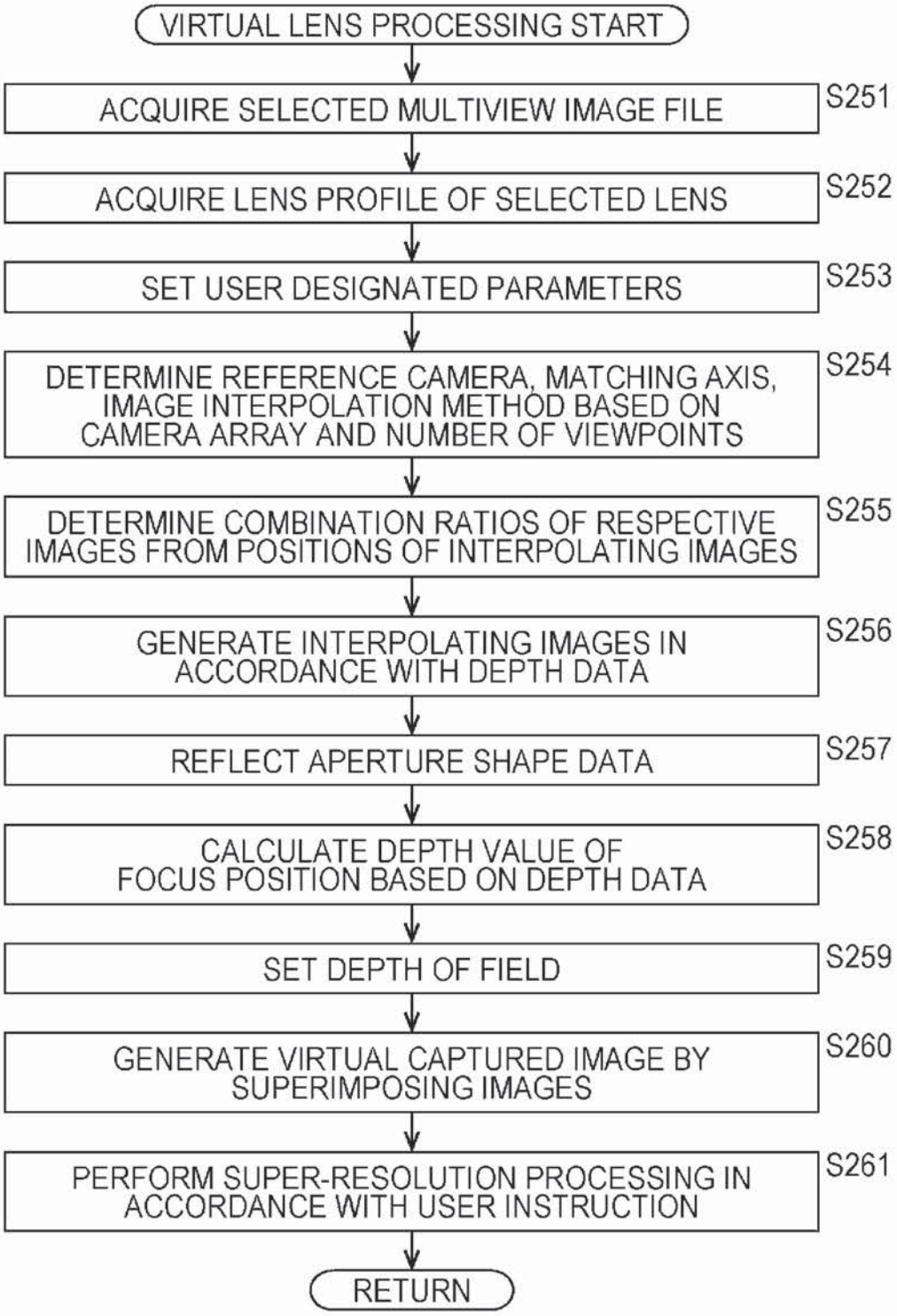
[Fig. 24]

FIG. 24



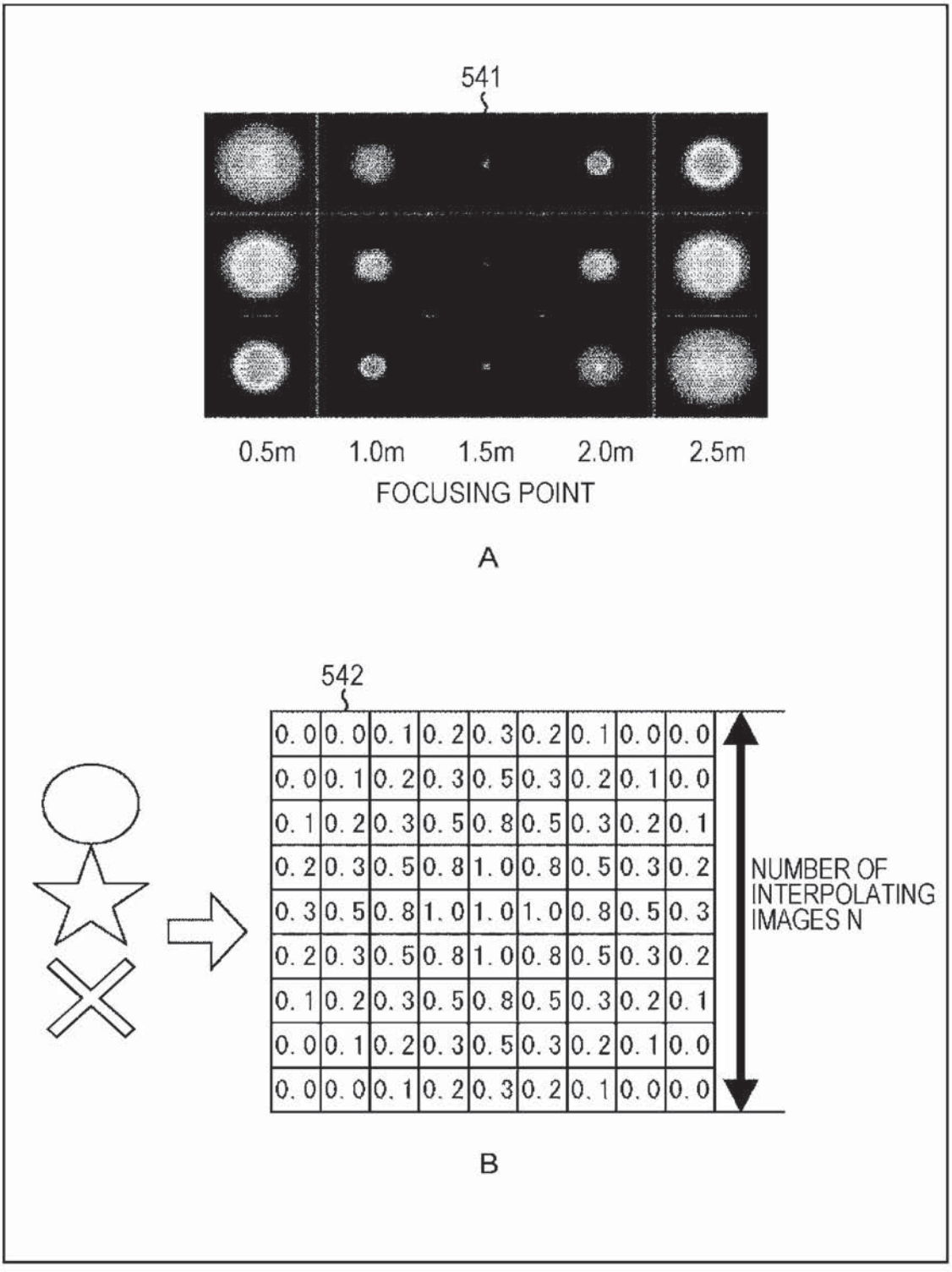
[Fig. 25]

FIG. 25


VIRTUAL LENS PROCESSING START
ACQUIRE SELECTED MULTIVIEW IMAGE FILE
S251
ACQUIRE LENS PROFILE OF SELECTED LENS
S252
SET USER DESIGNATED PARAMETERS
S253
DETERMINE REFERENCE CAMERA, MATCHING AXIS, IMAGE INTERPOLATION METHOD BASED ON CAMERA ARRAY AND NUMBER OF VIEWPOINTS
S254
DETERMINE COMBINATION RATIOS OF RESPECTIVE IMAGES FROM POSITIONS OF INTERPOLATING IMAGES
S255
GENERATE INTERPOLATING IMAGES IN ACCORDANCE WITH DEPTH DATA
S256
REFLECT APERTURE SHAPE DATA
S257
CALCULATE DEPTH VALUE OF FOCUS POSITION BASED ON DEPTH DATA
S258
SET DEPTH OF FIELD
S259
GENERATE VIRTUAL CAPTURED IMAGE BY SUPERIMPOSING IMAGES
S260
PERFORM SUPER-RESOLUTION PROCESSING IN ACCORDANCE WITH USER INSTRUCTION
S261
RETURN

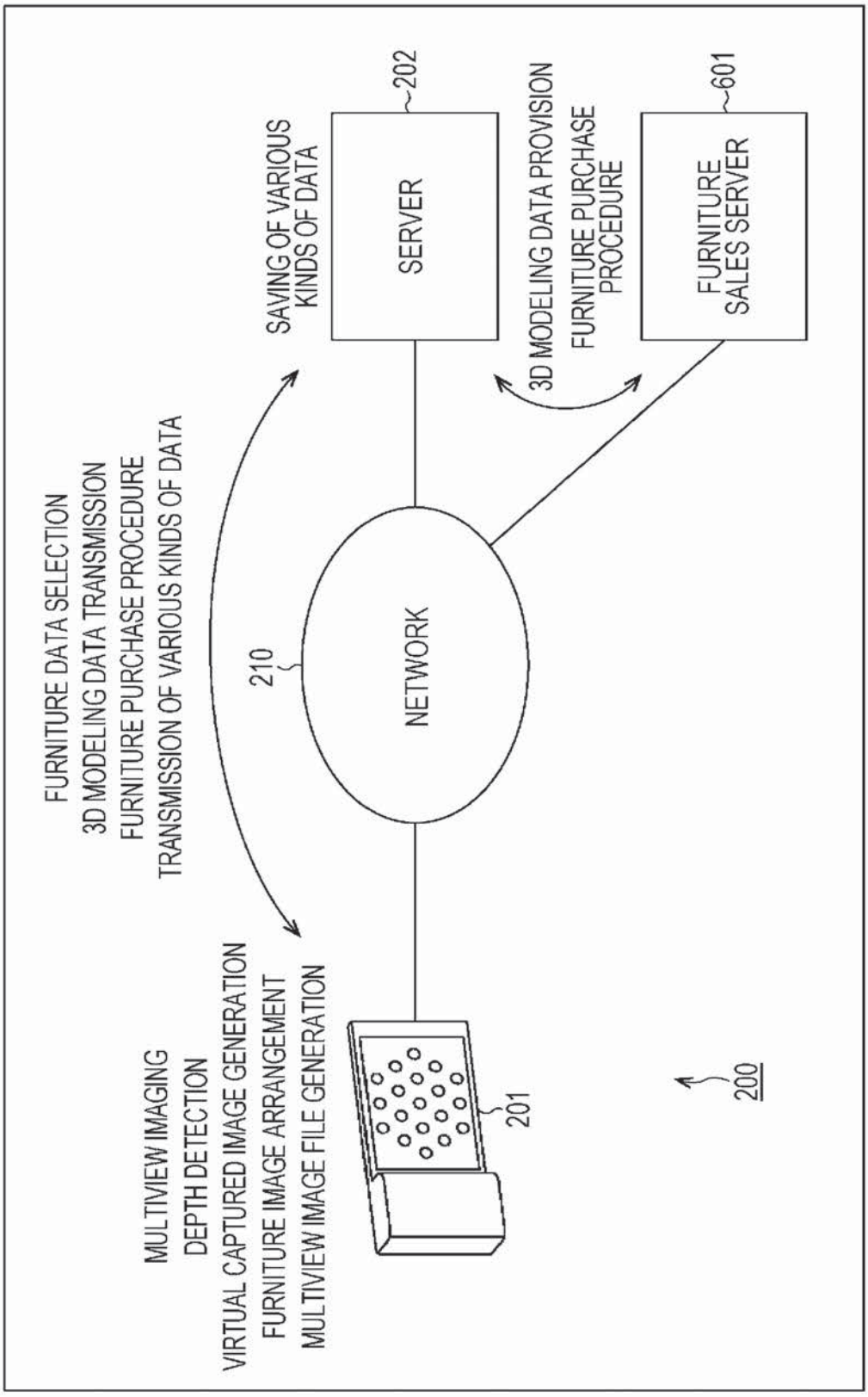
[Fig. 26]

FIG. 26


541
0.5m
1.0m
1.5m
2.0m
2.5m
FOCUSING POINT
A
542
0.0 0.0 0.1 0.2 0.3 0.2 0.1 0.0 0.0
0.0 0.1 0.2 0.3 0.5 0.3 0.2 0.1 0.0
0.1 0.2 0.3 0.5 0.8 0.5 0.3 0.2 0.1
0.2 0.3 0.5 0.8 1.0 0.8 0.5 0.3 0.2
0.3 0.5 0.8 1.0 1.0 1.0 0.8 0.5 0.3
0.2 0.3 0.5 0.8 1.0 0.8 0.5 0.3 0.2
0.1 0.2 0.3 0.5 0.8 0.5 0.3 0.2 0.1
0.0 0.1 0.2 0.3 0.5 0.3 0.2 0.1 0.0
0.0 0.0 0.1 0.2 0.3 0.2 0.1 0.0 0.0
NUMBER OF INTERPOLATING IMAGES N
B

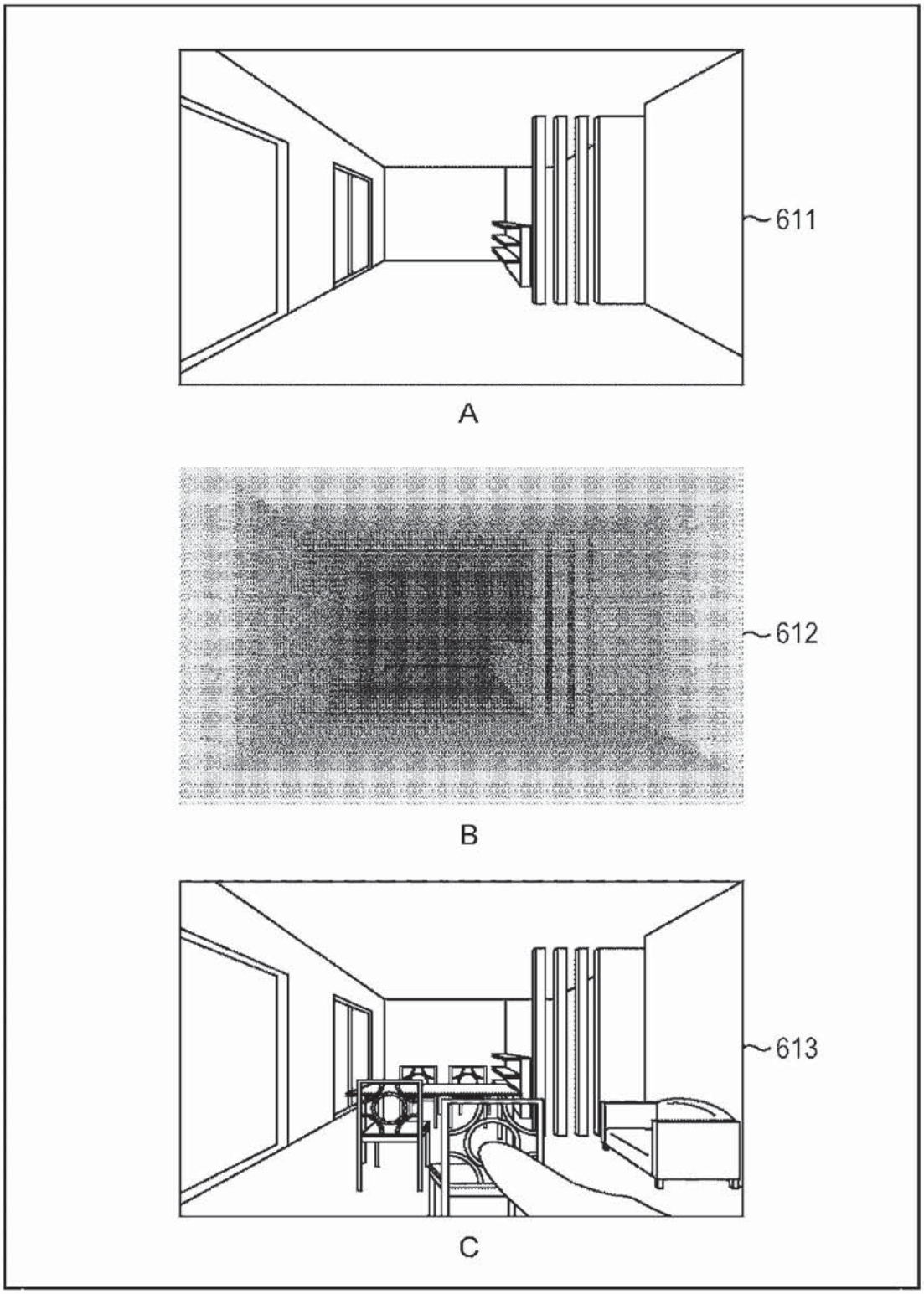
[Fig. 27]

FIG. 27


FURNITURE DATA SELECTION
3D MODELING DATA TRANSMISSION
FURNITURE PURCHASE PROCEDURE
TRANSMISSION OF VARIOUS KINDS OF DATA
MULTIVIEW IMAGING
DEPTH DETECTION
VIRTUAL CAPTURED IMAGE GENERATION
FURNITURE IMAGE ARRANGEMENT
MULTIVIEW IMAGE FILE GENERATION
SAVING OF VARIOUS KINDS OF DATA
3D MODELING DATA PROVISION
FURNITURE PURCHASE PROCEDURE
210
NETWORK
SERVER
202
FURNITURE SALES SERVER
601
201
200

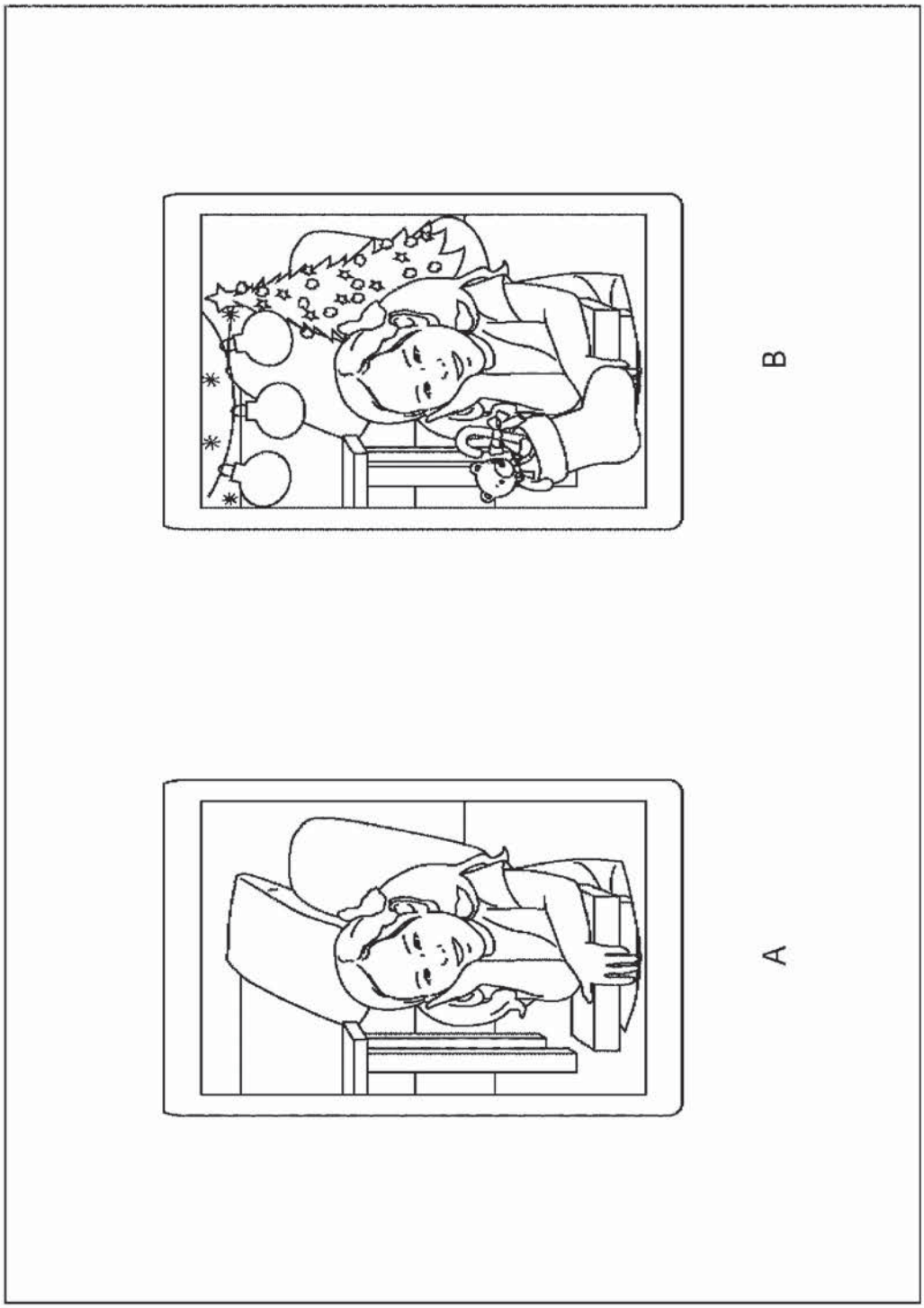
[Fig. 28]

FIG. 28



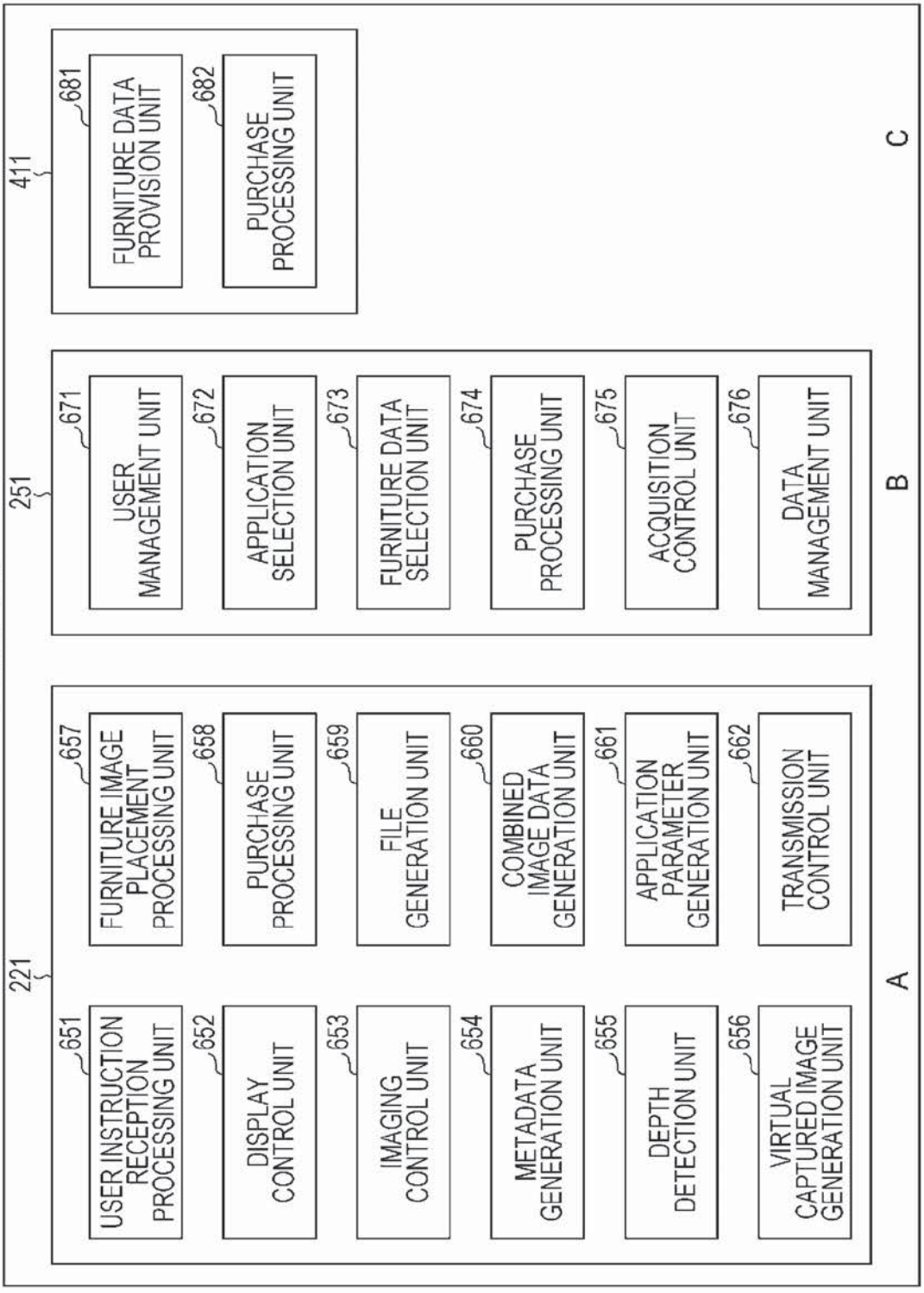
[Fig. 29]

FIG. 29



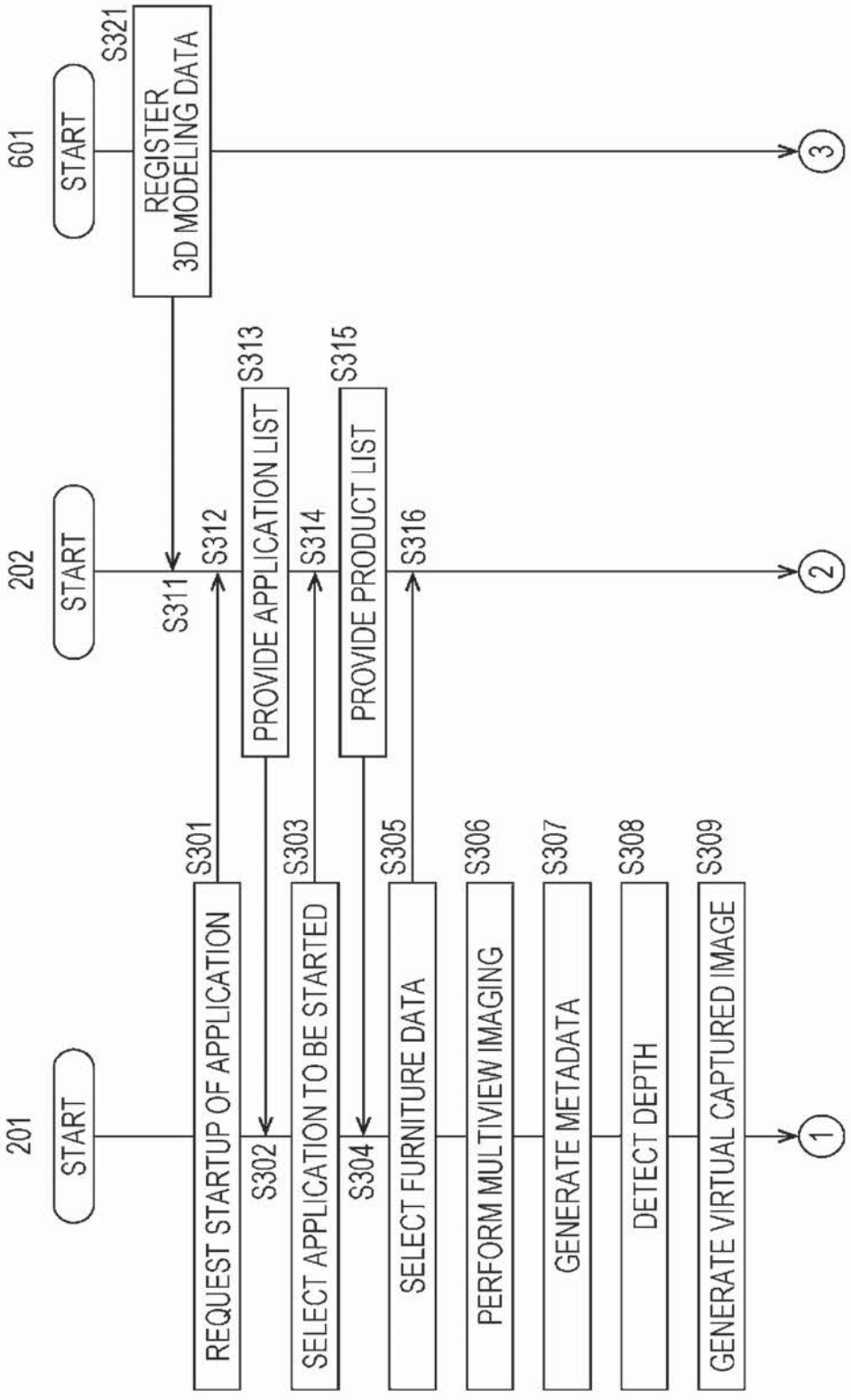
[Fig. 30]

FIG. 30


221
651 USER INSTRUCTION RECEPTION PROCESSING UNIT
652 DISPLAY CONTROL UNIT
653 IMAGING CONTROL UNIT
654 METADATA GENERATION UNIT
655 DEPTH DETECTION UNIT
656 VIRTUAL CAPTURED IMAGE GENERATION UNIT
657 FURNITURE IMAGE PLACEMENT PROCESSING UNIT
658 PURCHASE PROCESSING UNIT
659 FILE GENERATION UNIT
660 COMBINED IMAGE DATA GENERATION UNIT
661 APPLICATION PARAMETER GENERATION UNIT
662 TRANSMISSION CONTROL UNIT
A
251
671 USER MANAGEMENT UNIT
672 APPLICATION SELECTION UNIT
673 FURNITURE DATA SELECTION UNIT
674 PURCHASE PROCESSING UNIT
675 ACQUISITION CONTROL UNIT
676 DATA MANAGEMENT UNIT
B
411
681 FURNITURE DATA PROVISION UNIT
682 PURCHASE PROCESSING UNIT
C

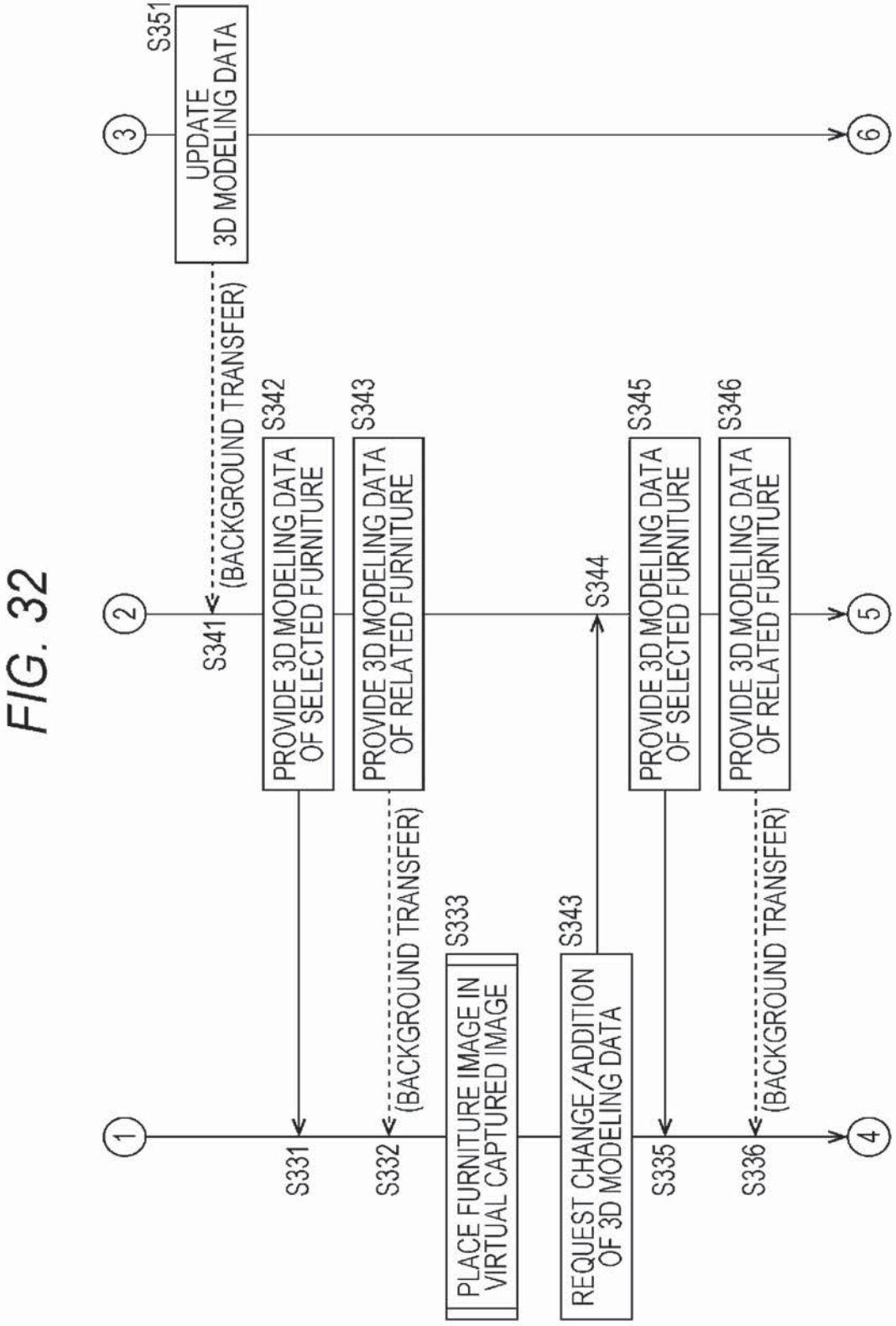
[Fig. 31]

FIG. 31


201
START
REQUEST STARTUP OF APPLICATION
S301
S302
SELECT APPLICATION TO BE STARTED
S303
S304
SELECT FURNITURE DATA
S305
PERFORM MULTIVIEW IMAGING
S306
GENERATE METADATA
S307
DETECT DEPTH
S308
GENERATE VIRTUAL CAPTURED IMAGE
S309
1
202
START
S311
S312
PROVIDE APPLICATION LIST
S313
S314
PROVIDE PRODUCT LIST
S315
S316
2
601
START
REGISTER 3D MODELING DATA
S321
3

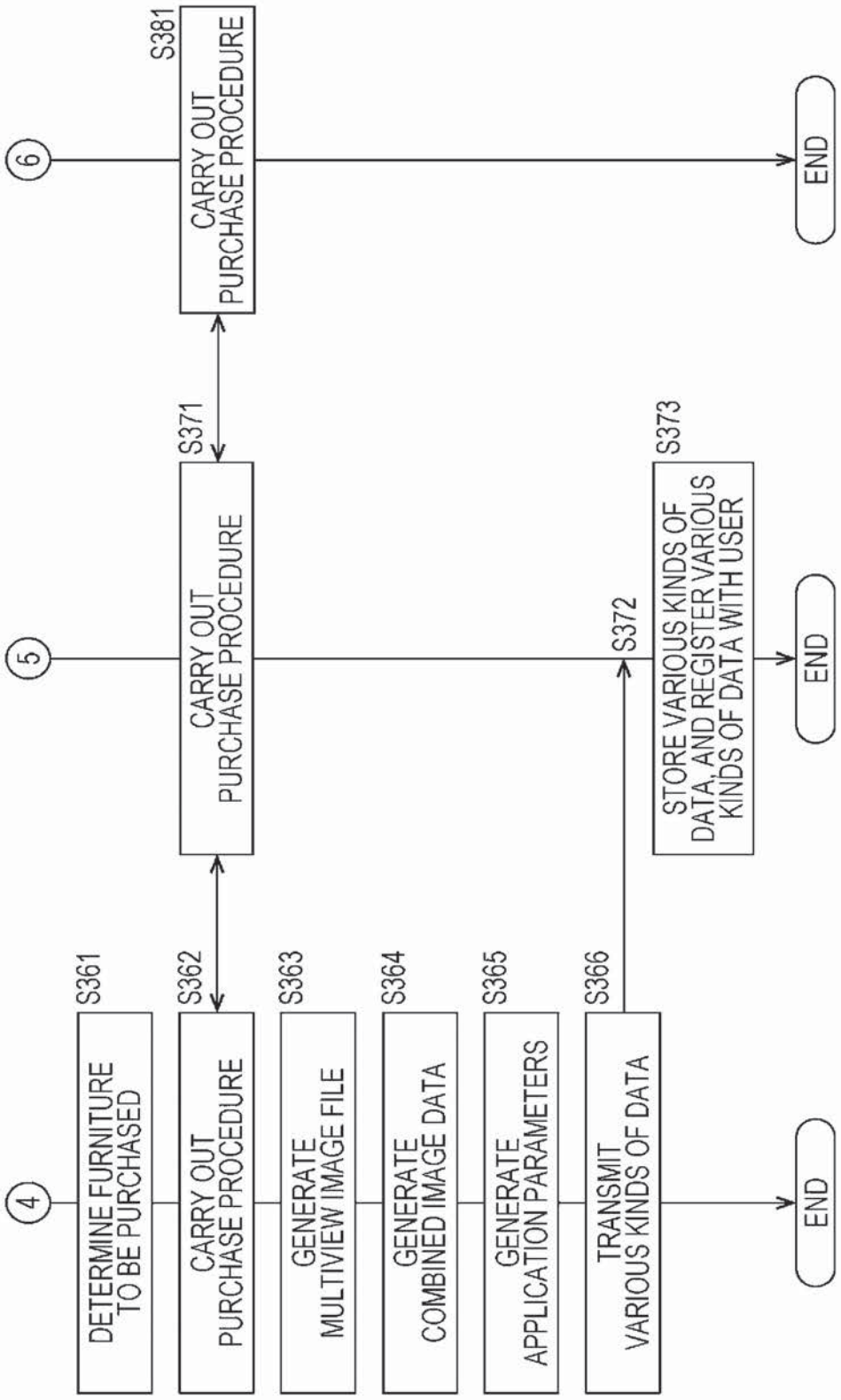
[Fig. 32]

FIG. 32


S351
UPDATE 3D MODELING DATA
3
6
(BACKGROUND TRANSFER)
S341
2
S342
PROVIDE 3D MODELING DATA OF SELECTED FURNITURE
S343
PROVIDE 3D MODELING DATA OF RELATED FURNITURE
S344
S345
PROVIDE 3D MODELING DATA OF SELECTED FURNITURE
S346
PROVIDE 3D MODELING DATA OF RELATED FURNITURE
5
1
S331
S332
(BACKGROUND TRANSFER)
S333
PLACE FURNITURE IMAGE IN VIRTUAL CAPTURED IMAGE
S343
REQUEST CHANGE/ADDITION OF 3D MODELING DATA
S335
S336
(BACKGROUND TRANSFER)
4

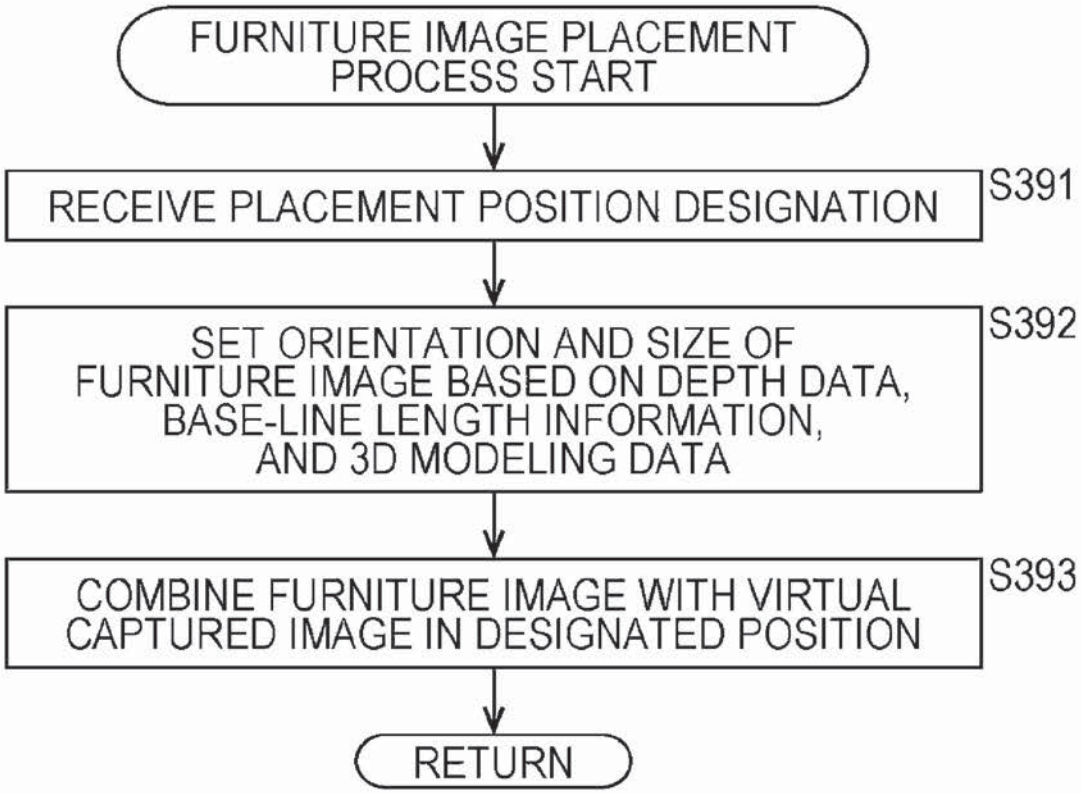
[Fig. 33]

FIG. 33


4
DETERMINE FURNITURE TO BE PURCHASED
S361
CARRY OUT PURCHASE PROCEDURE
S362
GENERATE MULTIVIEW IMAGE FILE
S363
GENERATE COMBINED IMAGE DATA
S364
GENERATE APPLICATION PARAMETERS
S365
TRANSMIT VARIOUS KINDS OF DATA
S366
END
5
CARRY OUT PURCHASE PROCEDURE
S371
S372
STORE VARIOUS KINDS OF DATA, AND REGISTER VARIOUS KINDS OF DATA WITH USER
S373
END
6
CARRY OUT PURCHASE PROCEDURE
S381
END

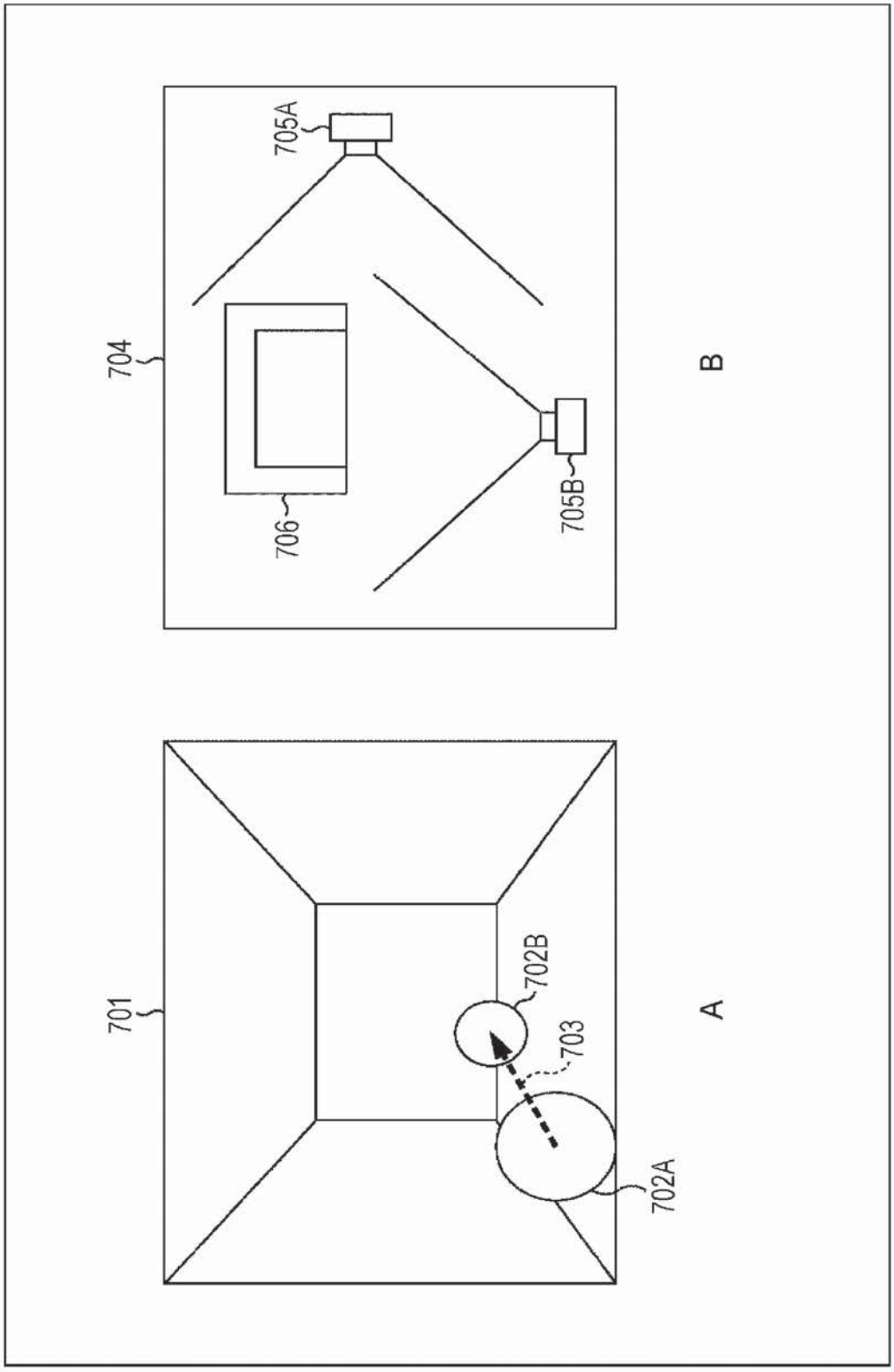
[Fig. 34]

FIG. 34


FURNITURE IMAGE PLACEMENT PROCESS START
RECEIVE PLACEMENT POSITION DESIGNATION
S391
SET ORIENTATION AND SIZE OF FURNITURE IMAGE BASED ON DEPTH DATA, BASE-LINE LENGTH INFORMATION, AND 3D MODELING DATA
S392
COMBINE FURNITURE IMAGE WITH VIRTUAL CAPTURED IMAGE IN DESIGNATED POSITION
S393
RETURN

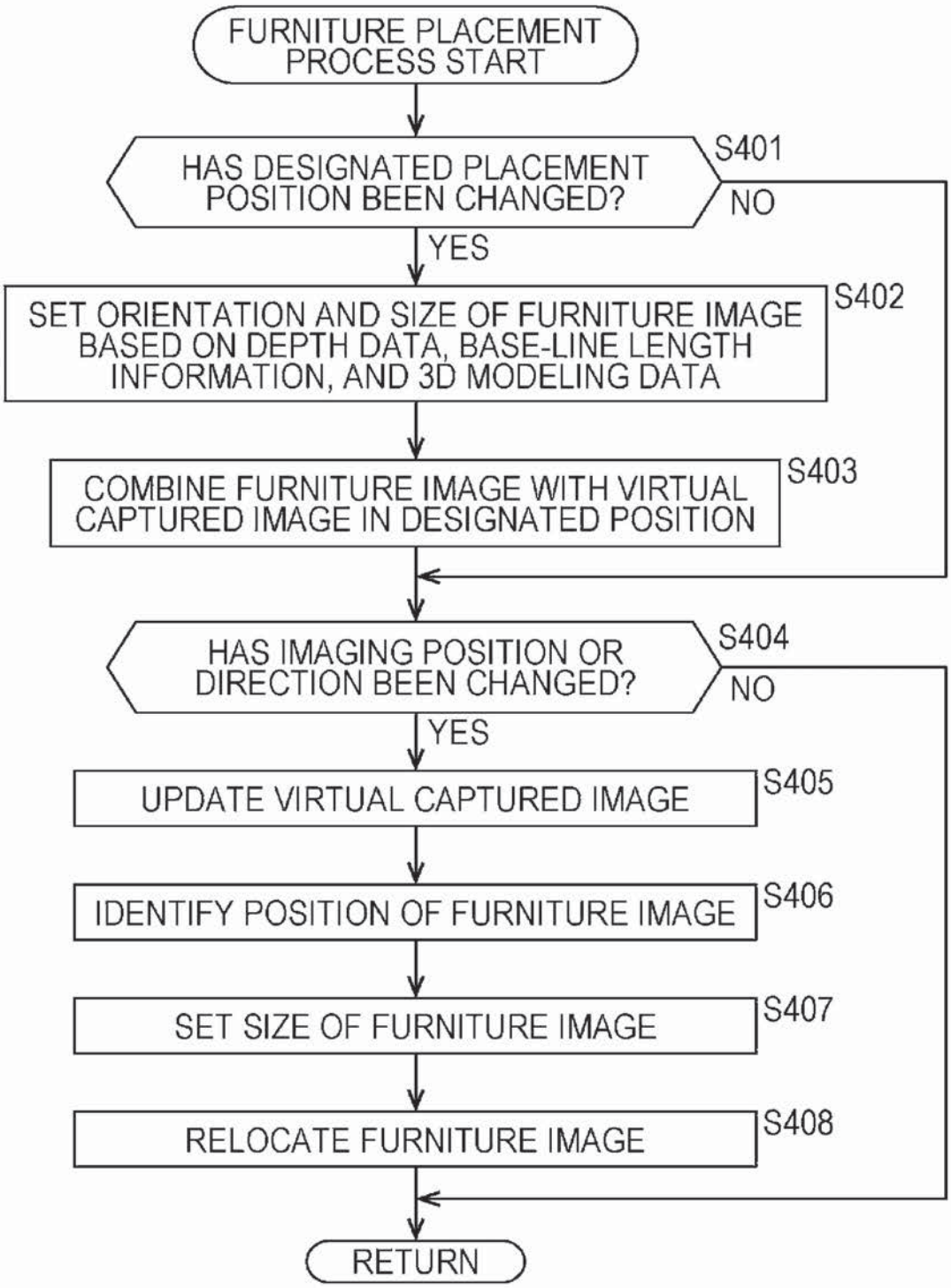
[Fig. 35]

FIG. 35



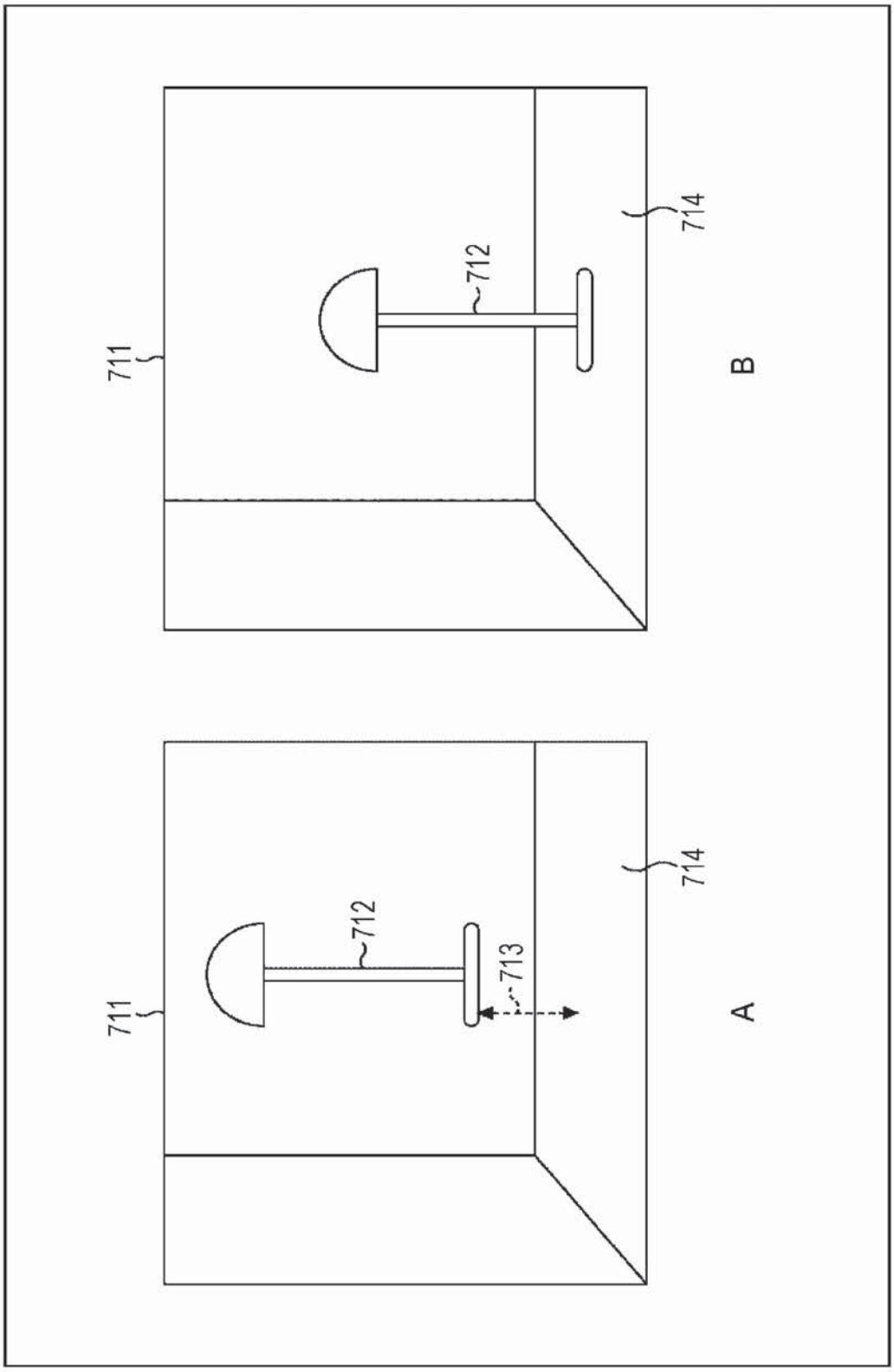
[Fig. 36]

FIG. 36


FURNITURE PLACEMENT PROCESS START
HAS DESIGNATED PLACEMENT POSITION BEEN CHANGED?
S401
NO
YES
SET ORIENTATION AND SIZE OF FURNITURE IMAGE BASED ON DEPTH DATA, BASE-LINE LENGTH INFORMATION, AND 3D MODELING DATA
S402
COMBINE FURNITURE IMAGE WITH VIRTUAL CAPTURED IMAGE IN DESIGNATED POSITION
S403
HAS IMAGING POSITION OR DIRECTION BEEN CHANGED?
S404
NO
YES
UPDATE VIRTUAL CAPTURED IMAGE
S405
IDENTIFY POSITION OF FURNITURE IMAGE
S406
SET SIZE OF FURNITURE IMAGE
S407
RELOCATE FURNITURE IMAGE
S408
RETURN

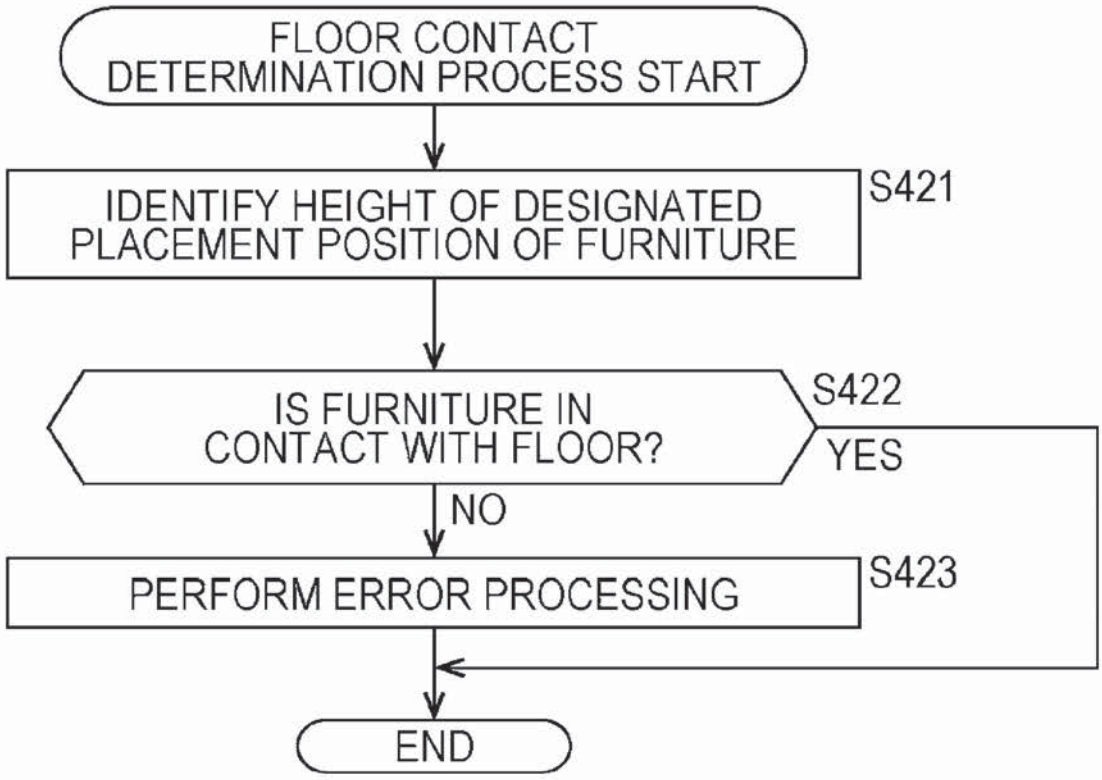
[Fig. 37]

FIG. 37



[Fig. 38]

FIG. 38


FLOOR CONTACT DETERMINATION PROCESS START
IDENTIFY HEIGHT OF DESIGNATED PLACEMENT POSITION OF FURNITURE
S421
IS FURNITURE IN CONTACT WITH FLOOR?
S422
YES
NO
PERFORM ERROR PROCESSING
S423
END

[Fig. 39]

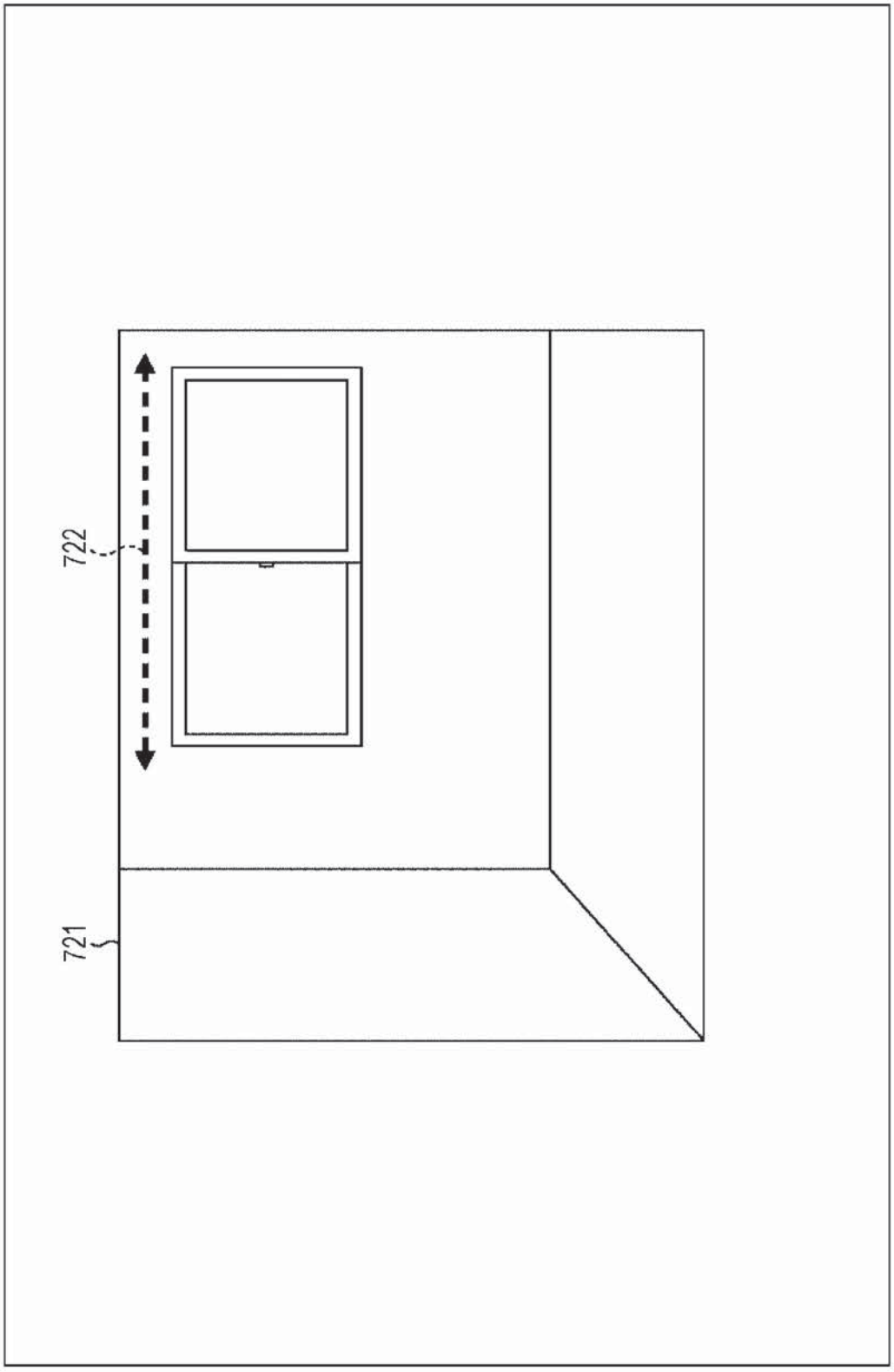
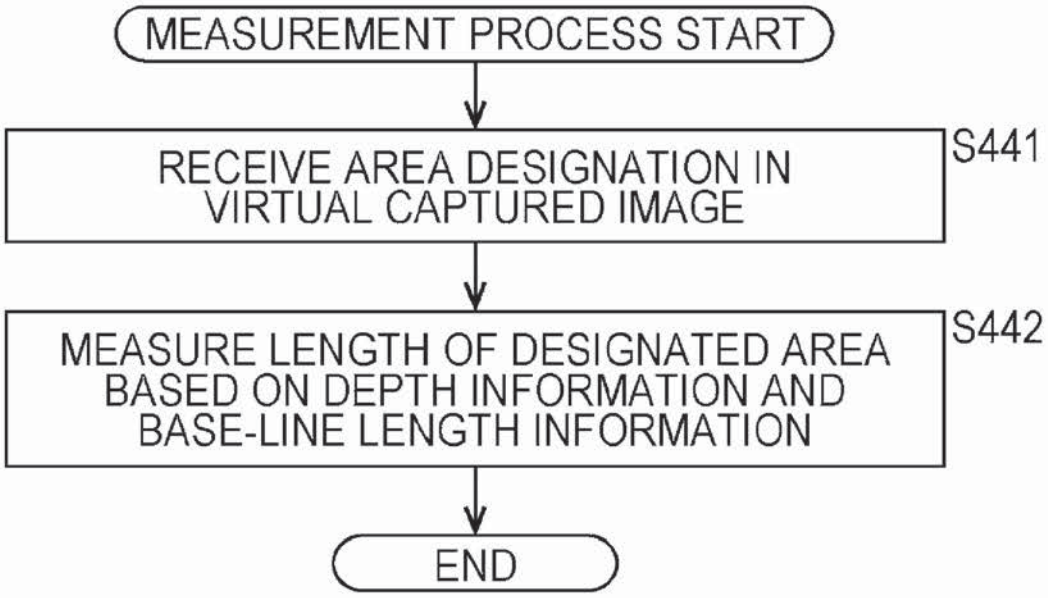


FIG. 39

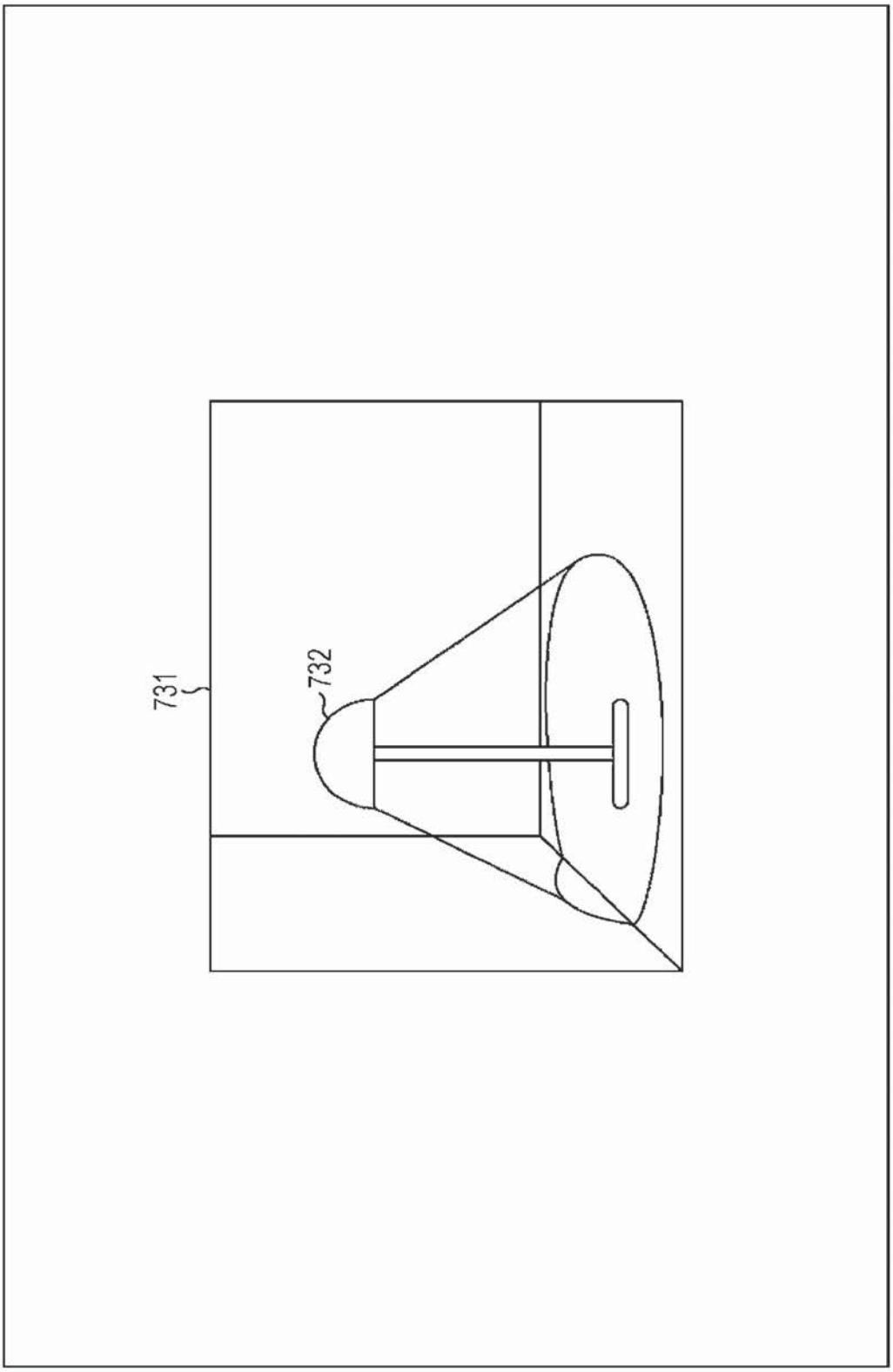
[Fig. 40]

FIG. 40


MEASUREMENT PROCESS START
RECEIVE AREA DESIGNATION IN VIRTUAL CAPTURED IMAGE
S441
MEASURE LENGTH OF DESIGNATED AREA BASED ON DEPTH INFORMATION AND BASE-LINE LENGTH INFORMATION
S442
END

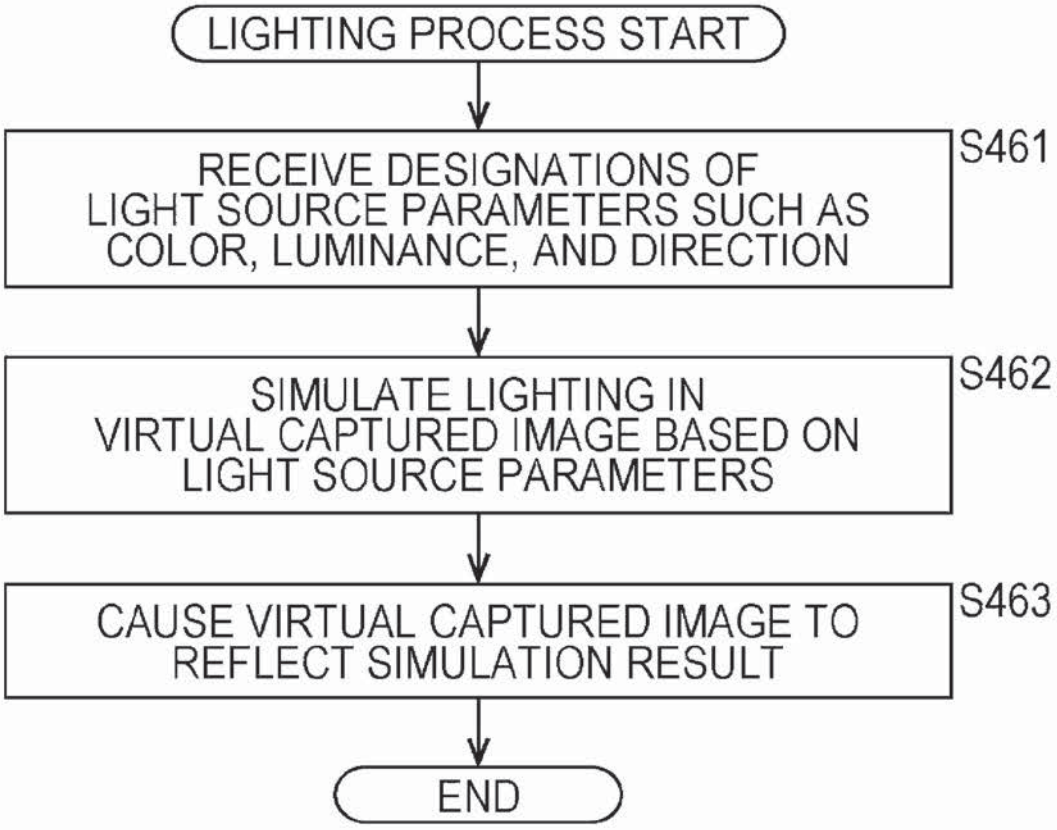
[Fig. 41]

FIG. 41



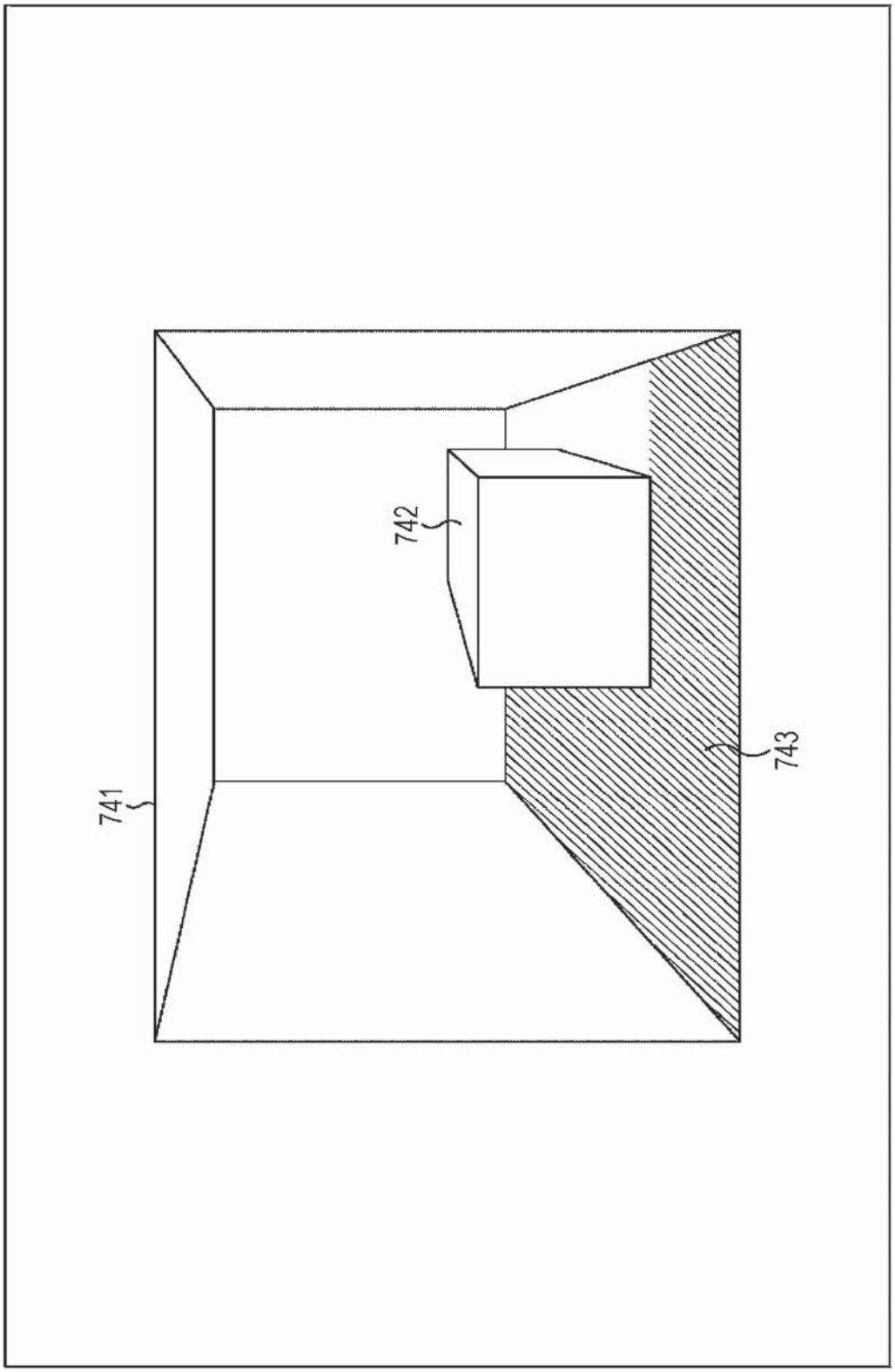
[Fig. 42]

FIG. 42


LIGHTING PROCESS START
RECEIVE DESIGNATIONS OF LIGHT SOURCE PARAMETERS SUCH AS COLOR, LUMINANCE, AND DIRECTION
S461
SIMULATE LIGHTING IN VIRTUAL CAPTURED IMAGE BASED ON LIGHT SOURCE PARAMETERS
S462
CAUSE VIRTUAL CAPTURED IMAGE TO REFLECT SIMULATION RESULT
S463
END

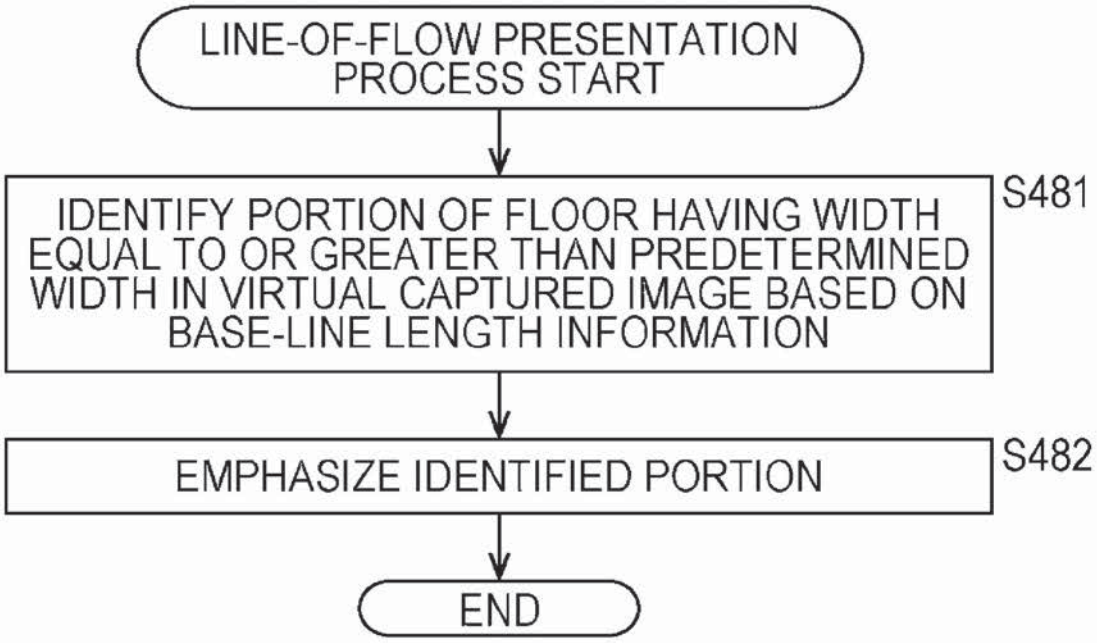
[Fig. 43]

FIG. 43



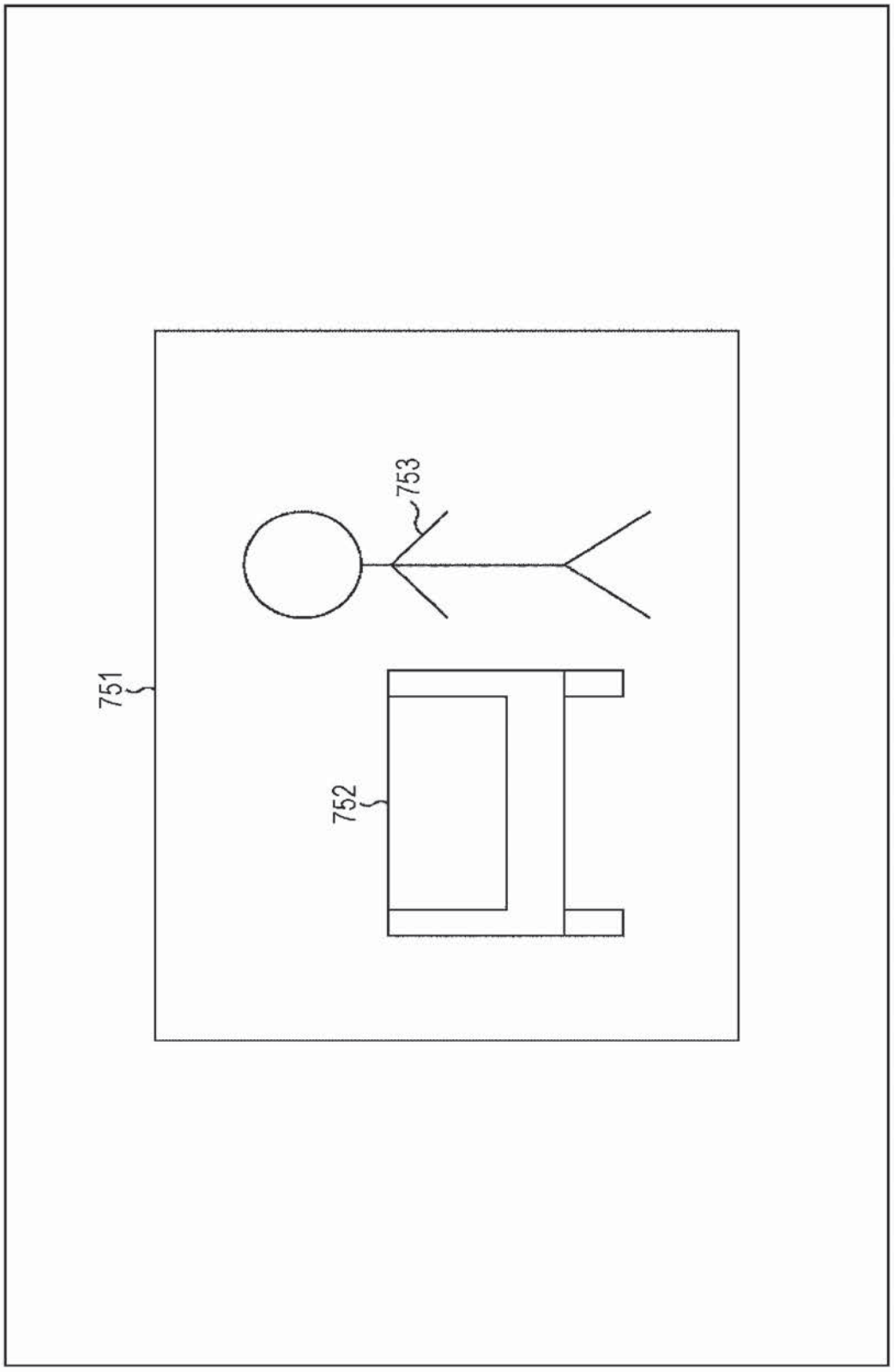
[Fig. 44]

FIG. 44


LINE-OF-FLOW PRESENTATION PROCESS START
IDENTIFY PORTION OF FLOOR HAVING WIDTH EQUAL TO OR GREATER THAN PREDETERMINED WIDTH IN VIRTUAL CAPTURED IMAGE BASED ON BASE-LINE LENGTH INFORMATION
S481
EMPHASIZE IDENTIFIED PORTION
S482
END

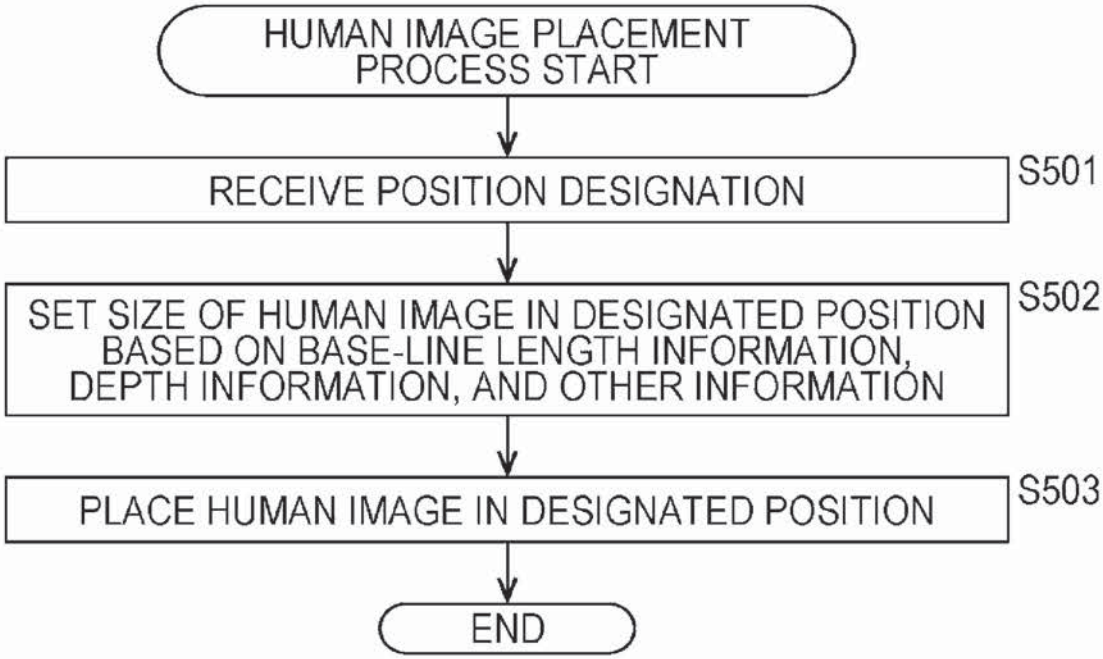
[Fig. 45]

FIG. 45



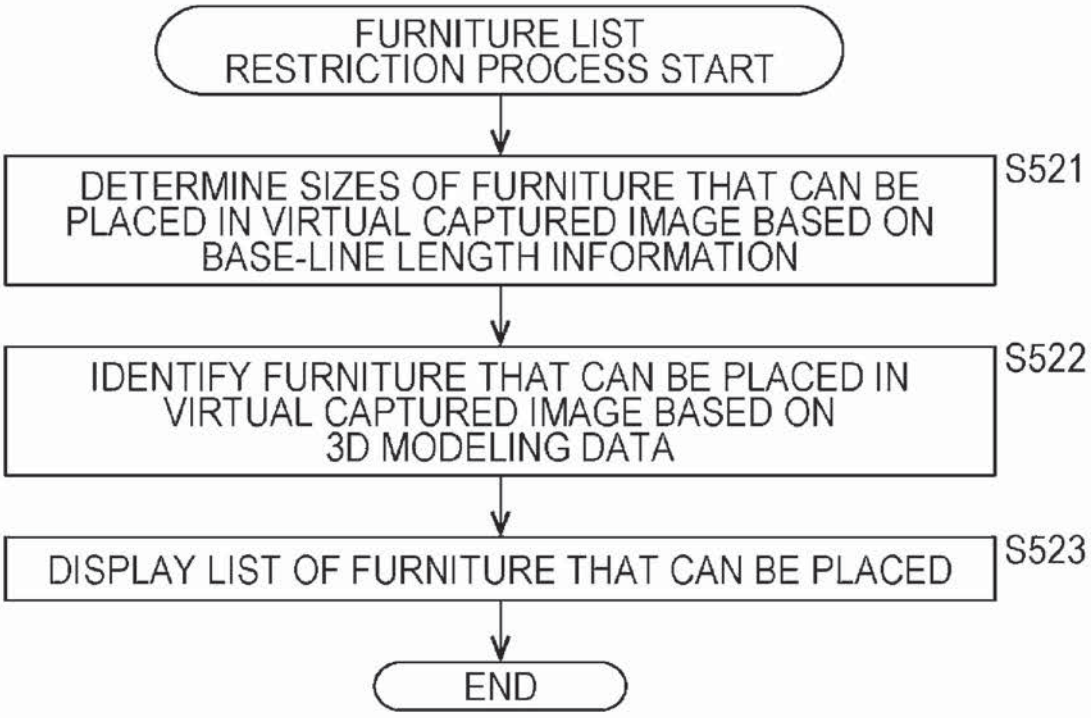
[Fig. 46]

FIG. 46


HUMAN IMAGE PLACEMENT PROCESS START
RECEIVE POSITION DESIGNATION
S501
SET SIZE OF HUMAN IMAGE IN DESIGNATED POSITION BASED ON BASE-LINE LENGTH INFORMATION, DEPTH INFORMATION, AND OTHER INFORMATION
S502
PLACE HUMAN IMAGE IN DESIGNATED POSITION
S503
END

[Fig. 47]

FIG. 47


FURNITURE LIST RESTRICTION PROCESS START
DETERMINE SIZES OF FURNITURE THAT CAN BE PLACED IN VIRTUAL CAPTURED IMAGE BASED ON BASE-LINE LENGTH INFORMATION
S521
IDENTIFY FURNITURE THAT CAN BE PLACED IN VIRTUAL CAPTURED IMAGE BASED ON 3D MODELING DATA
S522
DISPLAY LIST OF FURNITURE THAT CAN BE PLACED
S523
END

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2014/004507

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T3/00 H04N5/45 H04N13/02 H04N13/00
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)
G06T H04N

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 practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/029675 A1 (METAIO GMBH [DE]; BENHIMANE SELIM [DE]; LIEBERKNECHT SEBASTIAN [DE]; H) 7 March 2013 (2013-03-07) page 29, line 34 - page 30, line 27 page 33, line 25 - page 34, line 2 page 3, line 8 - line 10	1-23
A	WO 2011/102818 A1 (THOMSON LICENSING [FR]; BOYCE JILL MACDONALD [US]; RAMASWAMY KUMAR [US) 25 August 2011 (2011-08-25) claims 1,2	1-23
A	US 2007/156017 A1 (LAMPRECHT BEN [US] ET AL) 5 July 2007 (2007-07-05) claim 1; figure 6a	1-23

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 November 2014	13/11/2014

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	Thieme, Markus

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/JP2014/004507

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2013029675 A1	07-03-2013	CN 103988226 A	13-08-2014
		EP 2751777 A1	09-07-2014
		US 2014293016 A1	02-10-2014
		WO 2013029675 A1	07-03-2013
WO 2011102818 A1	25-08-2011	CN 102860014 A	02-01-2013
		EP 2537346 A1	26-12-2012
		JP 2013520866 A	06-06-2013
		KR 20120131185 A	04-12-2012
		US 2012314029 A1	13-12-2012
		WO 2011102818 A1	25-08-2011
US 2007156017 A1	05-07-2007	US 2007156017 A1	05-07-2007
		US 2011050852 A1	03-03-2011

Form PCT/ISA/210 (patent family annex) (April 2005)

Electronic Acknowledgement Receipt

EFS ID:	43227544
Application Number:	16046643
International Application Number:	
Confirmation Number:	1720
Title of Invention:	OPTICAL IMAGING SYSTEM WITH A PLURALITY OF SENSE CHANNELS
First Named Inventor/Applicant Name:	Angus Pacala
Customer Number:	20350
Filer:	William Leland Shaffer/LaRenda Meyer
Filer Authorized By:	William Leland Shaffer
Attorney Docket Number:	103033-P001USC2-1096583
Receipt Date:	12-JUL-2021
Filing Date:	26-JUL-2018
Time Stamp:	17:56:42
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Information Disclosure Statement (IDS) Form (SB08)	IDS-P001USC2.pdf	190668 735ff4509a4b0ba5426a425cd59af123a53cb6a	no	3

Warnings: