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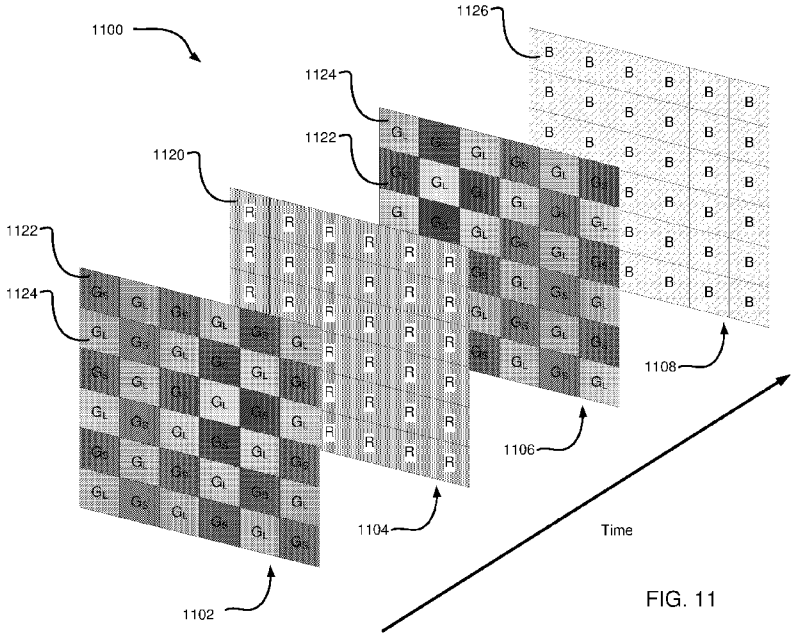


FIG. 11

(57) Abstract: Pulsed hyperspectral, fluorescence, and laser mapping imaging in a light deficient environment is disclosed. A system includes an emitter for emitting pulses of electromagnetic radiation and an image sensor comprising a pixel array for sensing reflected electromagnetic radiation. The system includes a controller configured to synchronize timing of the emitter and the image sensor. The system is such that at least a portion of the pulses of electromagnetic radiation emitted by the emitter comprises one or more of a hyperspectral emission, a fluorescence emission, or a laser mapping pattern.

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PULSED ILLUMINATION IN A HYPERSPECTRAL, FLUORESCENCE, AND LASER MAPPING IMAGING SYSTEM

TECHNICAL FIELD

[0001] This disclosure is directed to digital imaging and is particularly directed to hyperspectral imaging, fluorescence imaging, and/or laser mapping imaging in a light deficient environment.

BACKGROUND

[0002] Advances in technology have provided advances in imaging capabilities for medical use. An endoscope may be used to look inside a body and examine the interior of an organ or cavity of the body. Endoscopes are used for investigating a patient's symptoms, confirming a diagnosis, or providing medical treatment. A medical endoscope may be used for viewing a variety of body systems and parts such as the gastrointestinal tract, the respiratory tract, the urinary tract, the abdominal cavity, and so forth. Endoscopes may further be used for surgical procedures such as plastic surgery procedures, procedures performed on joints or bones, procedures performed on the neurological system, procedures performed within the abdominal cavity, and so forth.

[0003] In some instances of endoscopic imaging, it may be beneficial or necessary to view a space in color. A digital color image includes at least three layers, or "color channels," that cumulatively form an image with a range of hues. Each of the color channels measures the intensity and chrominance of light for a spectral band. Commonly, a digital color image includes a color channel for red, green, and blue spectral bands of light (this may be referred to as a Red Green Blue or RGB image). Each of the red, green, and blue color channels include brightness information for the red, green, or blue spectral band of light. The brightness information for the separate red, green, and blue layers are combined to create the color image. Because a color image is made up of separate layers, a conventional digital camera image sensor includes a color filter array that permits red, green, and blue visible light wavelengths to hit selected pixel sensors. Each individual pixel sensor element is made sensitive to red, green, or blue wavelengths and will only return image data for that wavelength. The image data from the total array of pixel sensors is combined to generate the RGB image. The at least three distinct types of pixel sensors consume significant physical space such that the complete pixel array cannot fit in the small distal end of an endoscope.

[0004] Because a traditional image sensor cannot fit in the distal end of an endoscope, the image sensor is traditionally located in a handpiece unit of an endoscope that is held by an endoscope operator and is not placed within the body cavity. In such an endoscope, light is transmitted along the length of the endoscope from the handpiece unit to the distal end of the endoscope. This configuration has significant limitations. Endoscopes with this configuration are delicate and can be easily misaligned or damaged when bumped or impacted during regular use. This can significantly degrade the quality of the images and necessitate that the endoscope be frequently repaired or replaced.

[0005] The traditional endoscope with the image sensor placed in the handpiece unit is further limited to capturing only color images. However, in some implementations, it may be desirable to capture images with fluorescence, hyperspectral, and/or laser mapping data in addition to color image data. Fluorescence imaging captures the emission of light by a substance that has absorbed electromagnetic radiation and "glows" as it emits a relaxation wavelength. Hyperspectral imaging can be used to identify different materials, biological processes, and chemical processes by emitting different partitions of electromagnetic radiation and assessing the spectral responses of materials. Laser mapping imaging can capture the surface shape of objects and landscapes and measure distances between objects within

a scene. Laser mapping imaging may further encompass tool tracking wherein the distances and/or dimensions of tools within a scene can be tracked relative to each other, relative to an imaging device, and/or relative to structures within the scene. In some implementations, it may be desirable to use one or more of fluorescence imaging, hyperspectral imaging, and/or laser mapping imaging in combination when imaging a scene.

[0006] However, applications of fluorescence, hyperspectral, and laser mapping technology known in the art typically require highly specialized equipment that may not be useful for multiple applications. Further, such technologies provide a limited view of an environment and typically must be used in conjunction with multiple separate systems and multiple separate image sensors that are made sensitive to specific bands of electromagnetic radiation. It is therefore desirable to develop an imaging system that can be used in a space constrained environment to generate fluorescence, hyperspectral, and or laser mapping imaging data.

[0007] In light of the foregoing, described herein are systems, methods, and devices for fluorescence, hyperspectral, and laser mapping imaging in a light deficient environment. Such systems, methods, and devices may provide multiple datasets for identifying critical structures in a body and providing precise and valuable information about a body cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Non-limiting and non-exhaustive implementations of the disclosure are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. Advantages of the disclosure will become better understood with regard to the following description and accompanying drawings where:

[0009] FIG. 1 is a schematic view of a system for digital imaging in a light deficient environment with a paired emitter and pixel array;

[0010] FIG. 2 is a system for providing illumination to a light deficient environment for endoscopic imaging;

[0011] FIG. 2A is a schematic diagram of complementary system hardware;

[0012] FIGS. 3A to 3D are illustrations of the operational cycles of a sensor used to construct an exposure frame;

[0013] FIG. 4A is a graphical representation of the operation of an embodiment of an electromagnetic emitter;

[0014] FIG. 4B is a graphical representation of varying the duration and magnitude of the emitted electromagnetic pulse to provide exposure control;

[0015] FIG. 5 is a graphical representation of an embodiment of the disclosure combining the operational cycles of a sensor, the electromagnetic emitter, and the emitted electromagnetic pulses of FIGS. 3A-4B, which demonstrate the imaging system during operation;

[0016] FIG. 6A is a schematic diagram of a process for recording a video with full spectrum light over a period of time from t(0) to t(1);

[0017] FIG. 6B is a schematic diagram of a process for recording a video by pulsing portioned spectrum light over a period of time from t(0) to t(1);

[0018] FIGS. 7A-7E illustrate schematic views of the processes over an interval of time for recording a frame of video for both full spectrum light and partitioned spectrum light;

[0019] FIG. 8 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate a YCbCr image frame;

[0020] FIG. 9 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate a YCbCr image frame;

[0021] FIG. 10 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate a YCbCr image frame;

[0022] FIG. 11 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate an RGB image frame;

[0023] FIG. 12 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate a YCbCr image frame;

[0024] FIG. 13 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate an RGB image frame;

[0025] FIG. 14 illustrates a pixel array of an image sensor comprising a plurality of pixels for sensing discrete exposure frames to generate a YCbCr image frame;

[0026] FIG. 15 is a schematic diagram of a process flow for applying correction algorithms and for applying frame reconstruction to a plurality of exposure frames for generating a YCbCr image frame with specialty data overlaid thereon;

[0027] FIG. 16 is a schematic diagram of a process flow for applying correction algorithms and frame reconstruction to a plurality of exposure frames for generating an RGB image frame with specialty data overlaid thereon;

[0028] FIG. 17 is a schematic diagram of color fusion hardware;

[0029] FIG. 18 illustrates two corresponding histograms of black-corrected signal for a region of an exposure frame captured with long exposure pixels and short exposure pixels;

[0030] FIG. 19A is a schematic diagram of an exposure frame pipeline for the Y-Cb-Y-Cr pulsing pattern;

[0031] FIG. 19B is a schematic diagram of an exposure frame pipeline of a 120Hz frame capture rate for generating a video stream;

[0032] FIG. 20 is a schematic diagram of a pattern reconstruction process for generating an RGB image with specialty data overlaid thereon by pulsing partitioned spectrums of light;

[0033] FIGS. 21A-21C illustrate a light source having a plurality of emitters;

[0034] FIG. 22 illustrates a single optical fiber outputting via a diffuser at an output to illuminate a scene in a light deficient environment;

[0035] FIG. 23 illustrates a portion of the electromagnetic spectrum divided into a plurality of different sub-spectrums which may be emitted by emitters of a light source in accordance with the principles and teachings of the disclosure;

[0036] FIG. 24 is a schematic diagram illustrating a timing sequence for emission and readout for generating an image frame comprising a plurality of exposure frames resulting from differing partitions of pulsed light;

[0037] FIG. 25 illustrates an imaging system including a single cut filter for filtering wavelengths of electromagnetic radiation;

[0038] FIG. 26 illustrates an imaging system comprising a multiple cut filter for filtering wavelengths of electromagnetic radiation;

[0039] FIG. 27 illustrates an example laser mapping pattern that may be pulsed by an imaging system;

[0040] FIGS. 28A and 28B illustrate an implementation having a plurality of pixel arrays for producing a three-dimensional image in accordance with the principles and teachings of the disclosure;

[0041] FIGS. 29A and 29B illustrate a perspective view and a side view, respectively, of an implementation of an imaging sensor built on a plurality of substrates, wherein a plurality of pixel columns forming the pixel array are located on the first substrate and a plurality of circuit columns are located on a second substrate and showing an electrical connection and communication between one column of pixels to its associated or corresponding column of circuitry; and

[0042] FIGS. 30A and 30B illustrate a perspective view and a side view, respectively, of an implementation of an imaging sensor having a plurality of pixel arrays for producing a three-dimensional image, wherein the plurality of pixel arrays and the image sensor are built on a plurality of substrates.

DETAILED DESCRIPTION

[0043] Disclosed herein are systems, methods, and devices for digital imaging that may be primarily suited to medical applications such as medical endoscopic imaging. An embodiment of the disclosure is an endoscopic system for color imaging and hyperspectral, fluorescence, and/or laser mapping imaging in a light deficient environment. Such methods, systems, and computer-based products disclosed herein provide imaging or diagnostic capabilities for use in medical robotics applications, such as the use of robotics for performing imaging procedures, surgical procedures, and the like.

[0044] Conventional endoscopes are designed such that the image sensor is placed at a proximal end of the device within a handpiece unit. This configuration requires that incident light travel the length of the endoscope by way of precisely coupled optical elements. The precise optical elements can easily be misaligned during regular use, and this can lead to image distortion or image loss. Embodiments of the disclosure place an image sensor within the highly space-constrained environment in the distal end of the endoscope itself. This provides greater optical simplicity when compared with implementations known in the art. However, an acceptable solution to this approach is by no means trivial and introduces its own set of engineering challenges.

[0045] There can be a noticeable loss to image quality when the overall size of an image sensor is minimized such that the image sensor can fit within the distal tip of an endoscope. The area of the pixel array of the image sensor can be reduced by reducing the number of pixels and/or the sensing area of each individual pixel. Each of these modifications impacts the resolution, sensitivity, and dynamic range of the resultant images. Traditional endoscopic imaging systems are geared toward sensing steady broadband illumination and providing color information by virtue of segmented pixel arrays such as the Bayer pattern array. In light of the deficiencies associated with segmented pixel arrays, disclosed herein are alternative systems and methods that use a monochromatic (may be referred to as “color agnostic”) pixel array that does not include individual pixel filters. In the embodiments disclosed herein, the color information is provided by pulsing an emitter with different wavelengths of electromagnetic radiation. The pulsed imaging system disclosed herein can generate color images with specialty imaging data overlaid thereon. The specialty imaging data includes one or more of hyperspectral, fluorescence, or laser mapping imaging data.

[0046] In an embodiment, the color information is determined by capturing independent exposure frames in response to pulses of different wavelengths of electromagnetic radiation. The alternative pulses may include red, green, and blue wavelengths for generating an RGB image frame consisting of a red exposure frame, a green exposure frame, and a blue exposure frame. In an alternative implementation, the alternative pulses may include luminance (“Y”), red

chrominance ("Cr"), and blue chrominance "(Cb") pulses of light for generating a YCbCr image frame consisting of luminance data, red chrominance data, and blue chrominance data. The color image frame further may further data from a specialty exposure frame overlaid on the RGB or YCbCr image frame. The specialty pulse may include one or more pulses of light for hyperspectral, fluorescence, and/or laser mapping imaging. Alternating the wavelengths of the pulsed electromagnetic radiation allows the full pixel array to be exploited and avoids the artifacts introduced by Bayer pattern pixel arrays.

[0047] In some instances, it is desirable to generate endoscopic imaging with multiple data types or multiple images overlaid on one another. For example, it may be desirable to generate a color ("RGB") image that further includes hyperspectral, fluorescence, and/or laser mapping imaging data overlaid on the RGB image. An overlaid image of this nature may enable a medical practitioner or computer program to identify highly accurate dimensions and three-dimensional topologies of critical body structures and further identify distances between tools and other structures within the light deficient environment based on the laser mapping data. Historically, this would require the use of multiple sensor systems including an image sensor for color imaging and one or more additional image sensors for hyperspectral, fluorescence, or laser mapping imaging. In such systems, the multiple image sensors would have multiple types of pixel sensors that are each sensitive to distinct ranges of electromagnetic radiation. In systems known in the art, this includes the three separate types of pixel sensors for generating an RGB color image along with additional sensors and systems for generating the hyperspectral, fluorescence, and laser mapping data. These multiple different sensors consume a prohibitively large physical space and cannot be located at a distal tip of the endoscope. In systems known in the art, the camera or cameras are not placed at the distal tip of the endoscope and are instead placed in an endoscope handpiece or robotic unit. This introduces numerous disadvantages and causes the endoscope to be very delicate. The delicate endoscope may be damaged and image quality may be degraded when the endoscope is bumped or impacted during use. Considering the foregoing, disclosed herein are systems, methods, and devices for endoscopic imaging in a light deficient environment. The systems, methods, and devices disclosed herein provide means for employing multiple imaging techniques in a single imaging session while permitting one or more image sensors to be disposed in a distal tip of the endoscope.

[0048] The fluorescence imaging techniques discussed herein can be used in combination with one or more fluorescent reagents or dyes. The location of a reagent can be identified by emitting an excitation wavelength of electromagnetic radiation that causes the reagent to fluoresce. The relaxation wavelength emitted by the reagent can be read by an image sensor to identify the location of the reagent within a scene. Depending on the type of reagent that is used, the location of the reagent may further indicate the location of critical structures such as certain types of tissue, cancerous cells versus non-cancerous cells, and so forth.

[0049] The hyperspectral imaging techniques discussed herein can be used to "see through" layers of tissue in the foreground of a scene to identify specific types of tissue and/or specific biological or chemical processes. Hyperspectral imaging can be used in the medical context to quantitatively track the process of a disease and to determine tissue pathology. Additionally, hyperspectral imaging can be used to identify critical structures such as nervous tissue, muscle tissue, cancerous cells, and so forth. In an embodiment, partitions of electromagnetic radiation are pulsed, and data is gathered regarding the spectral responses of different types of tissue in response to the partitions of electromagnetic radiation. A datastore of spectral responses can be generated and analyzed to assess a scene and predict which tissues are present within the scene based on the sensed spectral responses.

[0050] The laser mapping imaging techniques discussed herein can be assessed to generate a three-dimensional landscape map of a scene and to calculate distances between objects within the scene. The laser mapping data can be used in conjunction with fluorescence imaging and/or hyperspectral imaging to calculate the precise location and dimensions of critical structures. For example, the location and boundaries of a critical structure may be identified with the fluorescence and/or hyperspectral imaging. The precise measurements for the location of the critical structure, the dimensions of the critical structure, and the distance from the critical structure to other objects can then be calculated based on the laser mapping data.

Hyperspectral Imaging

[0051] In an embodiment, the systems, methods, and devices disclosed herein provide means for generating hyperspectral imaging data in a light deficient environment. Spectral imaging uses multiple bands across the electromagnetic spectrum. This is different from conventional cameras that only capture light across the three wavelengths based in the visible spectrum that are discernable by the human eye, including the red, green, and blue wavelengths to generate an RGB image. Spectral imaging may use any wavelength bands in the electromagnetic spectrum, including infrared wavelengths, the visible spectrum, the ultraviolet spectrum, x-ray wavelengths, or any suitable combination of various wavelength bands.

[0052] Hyperspectral imaging was originally developed for applications in mining and geology. Unlike a normal camera image that provides limited information to the human eye, hyperspectral imaging can identify specific minerals based on the spectral signatures of the different minerals. Hyperspectral imaging can be useful even when captured in aerial images and can provide information about, for example, oil or gas leakages from pipelines or natural wells and their effects on nearby vegetation. This information is collected based on the spectral signatures of certain materials, objects, or processes that may be identified by hyperspectral imaging.

[0053] Hyperspectral imaging includes spectroscopy and digital photography. In an embodiment of hyperspectral imaging, a complete spectrum or some spectral information is collected at every pixel in an image plane. The goal of hyperspectral imaging may vary for different applications. In one application, the goal of hyperspectral imaging is to obtain the entire electromagnetic spectrum of each pixel in an image scene. This may enable certain objects to be found that might otherwise not be identifiable under the visible light wavelength bands. This may enable certain materials or tissues to be identified with precision when those materials or tissues might not be identifiable under the visible light wavelength bands. Further, this may enable certain processes to be detected by capturing an image across all wavelengths of the electromagnetic spectrum.

[0054] In an embodiment of the disclosure, an endoscope system illuminates a source and pulses electromagnetic radiation for spectral or hyperspectral imaging. Spectral imaging uses multiple bands across the electromagnetic spectrum. This is different from conventional cameras that only capture light across the three wavelengths based in the visible spectrum that are discernable by the human eye, including the red, green, and blue wavelengths to generate an RGB image. Spectral imaging may use any wavelength bands in the electromagnetic spectrum, including infrared wavelengths, the visible spectrum, the ultraviolet spectrum, x-ray wavelengths, or any suitable combination of various wavelength bands. Spectral imaging may overlay imaging generated based on non-visible bands (*e.g.*, infrared) on top of imaging based on visible bands (*e.g.* a standard RGB image) to provide additional information that is easily discernable by a person or computer algorithm.

[0055] Hyperspectral imaging enables numerous advantages over conventional imaging. The information obtained by hyperspectral imaging enables medical practitioners and/or computer-implemented programs to precisely identify certain tissues or conditions that may not be possible to identify with RGB imaging. Additionally, hyperspectral imaging may be used during medical procedures to provide image-guided surgery that enables a medical practitioner to, for example, view tissues located behind certain tissues or fluids, identify atypical cancerous cells in contrast with typical healthy cells, identify certain tissues or conditions, identify critical structures, and so forth. Hyperspectral imaging provides specialized diagnostic information about tissue physiology, morphology, and composition that cannot be generated with conventional imaging.

[0056] Hyperspectral imaging may provide particular advantages over conventional imaging in medical applications. The information obtained by hyperspectral imaging can enable medical practitioners and/or computer-implemented programs to precisely identify certain tissues or conditions that may lead to diagnoses that may not be possible or may be less accurate if using conventional imaging such as RGB imaging. Additionally, hyperspectral imaging may be used during medical procedures to provide image-guided surgery that may enable a medical practitioner to, for example, view tissues located behind certain tissues or fluids, identify atypical cancerous cells in contrast with typical healthy cells, identify certain tissues or conditions, identify critical structures and so forth. Hyperspectral imaging may provide specialized diagnostic information about tissue physiology, morphology, and composition that cannot be generated with conventional imaging.

[0057] Endoscopic hyperspectral imaging may present advantages over conventional imaging in various applications and implementations of the disclosure. In medical implementations, endoscopic hyperspectral imaging may permit a practitioner or computer-implemented program to discern, for example, nervous tissue, muscle tissue, various vessels, the direction of blood flow, and so forth. Hyperspectral imaging may enable atypical cancerous tissue to be precisely differentiated from typical healthy tissue and may therefore enable a practitioner or computer-implemented program to discern the boundary of a cancerous tumor during an operation or investigative imaging. Additionally, hyperspectral imaging in a light deficient environment as disclosed herein may be combined with the use of a reagent or dye to enable further differentiation between certain tissues or substances. In such an embodiment, a reagent or dye may be fluoresced by a specific wavelength band in the electromagnetic spectrum and therefore provide information specific to the purpose of that reagent or dye. The systems, methods, and devices disclosed herein may enable any number of wavelength bands to be pulsed such that one or more reagents or dyes may be fluoresced at different times, and further so that one or more partitions of electromagnetic radiation may be pulsed for hyperspectral imaging in the same imaging session. In certain implementations, this enables the identification or investigation of a number of medical conditions during a single imaging procedure.

Fluorescence Imaging

[0058] The systems, methods, and devices disclosed herein provide means for generating fluorescence imaging data in a light deficient environment. The fluorescence imaging data may be used to identify certain materials, tissues, components, or processes within a body cavity or other light deficient environment. In certain embodiments, fluorescence imaging is provided to a medical practitioner or computer-implemented program to enable the identification of certain structures or tissues within a body. Such fluorescence imaging data may be overlaid on black-and-white or RGB images to provide additional information and context.

[0059] Fluorescence is the emission of light by a substance that has absorbed light or other electromagnetic radiation. Certain fluorescent materials may "glow" or emit a distinct color that is visible to the human eye when the fluorescent material is subjected to ultraviolet light or other wavelengths of electromagnetic radiation. Certain fluorescent materials will cease to glow nearly immediately when the radiation source stops.

[0060] Fluorescence occurs when an orbital electron of a molecule, atom, or nanostructure is excited by light or other electromagnetic radiation, and then relaxes to its ground state by emitting a photon from the excited state. The specific frequencies of electromagnetic radiation that excite the orbital electron, or are emitted by the photon during relaxation, are dependent on the particular atom, molecule, or nanostructure. In most cases, the light emitted by the substance has a longer wavelength, and therefore lower energy, than the radiation that was absorbed by the substance. However, when the absorbed electromagnetic radiation is intense, it is possible for one electron to absorb two photons. This two-photon absorption can lead to emission of radiation having a shorter wavelength, and therefore higher energy, than the absorbed radiation. Additionally, the emitted radiation may also be the same wavelength as the absorbed radiation.

[0061] Fluorescence imaging has numerous practical applications, including mineralogy, gemology, medicine, spectroscopy for chemical sensors, detecting biological processes or signals, and so forth. Fluorescence may particularly be used in biochemistry and medicine as a non-destructive means for tracking or analyzing biological molecules. The biological molecules, including certain tissues or structures, may be tracked by analyzing the fluorescent emission of the biological molecules after being excited by a certain wavelength of electromagnetic radiation. However, relatively few cellular components are naturally fluorescent. In certain implementations, it may be desirable to visualize a certain tissue, structure, chemical process, or biological process that is not intrinsically fluorescent. In such an implementation, the body may be administered a dye or reagent that may include a molecule, protein, or quantum dot having fluorescent properties. The reagent or dye may then fluoresce after being excited by a certain wavelength of electromagnetic radiation. Different reagents or dyes may include different molecules, proteins, and/or quantum dots that will fluoresce at particular wavelengths of electromagnetic radiation. Thus, it may be necessary to excite the reagent or dye with a specialized band of electromagnetic radiation to achieve fluorescence and identify the desired tissue, structure, or process in the body.

[0062] Fluorescence imaging may provide valuable information in the medical field that may be used for diagnostic purposes and/or may be visualized in real-time during a medical procedure. Specialized reagents or dyes may be administered to a body to fluoresce certain tissues, structures, chemical processes, or biological processes. The fluorescence of the reagent or dye may highlight body structures such as blood vessels, nerves, particular organs, and so forth. Additionally, the fluorescence of the reagent or dye may highlight conditions or diseases such as cancerous cells or cells experiencing a certain biological or chemical process that may be associated with a condition or disease. The fluorescence imaging may be used in real-time by a medical practitioner or computer program for differentiating between, for example, cancerous and non-cancerous cells during a surgical tumor extraction. The fluorescence imaging may further be used as a non-destructive means for tracking and visualizing over time a condition in the body that would otherwise not be visible by the human eye or distinguishable in an RGB image.

[0063] The systems, methods, and devices for generating fluorescence imaging data may be used in coordination with reagents or dyes. Some reagents or dyes are known to attach to certain types of tissues and fluoresce at specific wavelengths of the electromagnetic spectrum. In an implementation, a reagent or dye is administered to a patient that is

configured to fluoresce when activated by certain wavelengths of light. The endoscopic imaging system disclosed herein is used to excite and fluoresce the reagent or dye. The fluorescence of the reagent or dye is captured by the endoscopic imaging system to aid in the identification of tissues or structures in the body cavity. In an implementation, a patient is administered a plurality of reagents or dyes that are each configured to fluoresce at different wavelengths and/or provide an indication of different structures, tissues, chemical reactions, biological processes, and so forth. In such an implementation, the endoscopic imaging system emits each of the applicable wavelengths to fluoresce each of the applicable reagents or dyes. This may negate the need to perform individual imaging procedures for each of the plurality of reagents or dyes.

[0064] Imaging reagents can enhance imaging capabilities in pharmaceutical, medical, biotechnology, diagnostic, and medical procedure industries. Many imaging techniques such as X-ray, computer tomography (CT), ultrasound, magnetic resonance imaging (MRI), and nuclear medicine, mainly analyze anatomy and morphology and are unable to detect changes at the molecular level. Fluorescent reagents, dyes, and probes, including quantum dot nanoparticles and fluorescent proteins, assist medical imaging technologies by providing additional information about certain tissues, structures, chemical processes, and/or biological processes that are present within the imaging region. Imaging using fluorescent reagents enables cell tracking and/or the tracking of certain molecular biomarkers. Fluorescent reagents may be applied for imaging cancer, infection, inflammation, stem cell biology, and others. Numerous fluorescent reagents and dyes are being developed and applied for visualizing and tracking biological processes in a non-destructive manner. Such fluorescent reagents may be excited by a certain wavelength or band of wavelengths of electromagnetic radiation. Similarly, those fluorescent reagents may emit relaxation energy at a certain wavelength or band of wavelengths when fluorescing, and the emitted relaxation energy may be read by a sensor to determine the location and/or boundaries of the reagent or dye.

[0065] In an embodiment of the disclosure, an endoscopic imaging system pulses electromagnetic radiation for exciting an electron in a fluorescent reagent or dye. The endoscopic imaging system may pulse multiple different wavelengths of electromagnetic radiation for fluorescing multiple different reagents or dyes during a single imaging session. The endoscope includes an image sensor that is sensitive to the relaxation wavelength(s) of the one or more reagents or dyes. The imaging data generated by the image sensor can be used to identify a location and boundary of the one or more reagents or dyes. The endoscope system may further pulse electromagnetic radiation in red, green, and blue bands of visible light such that the fluorescence imaging can be overlaid on an RGB video stream.

Laser Mapping Imaging

[0066] In an embodiment, the systems, methods, and devices disclosed herein provide means for generating laser mapping data with an endoscopic imaging system. Laser mapping data can be used to determine precise measurements and topographical outlines of a scene. In one implementation, laser mapping data is used to determine precise measurements between, for example, structures or organs in a body cavity, devices or tools in the body cavity, and/or critical structures in the body cavity. As discussed herein, the term “laser mapping” may encompass technologies referred to as laser mapping, laser scanning, topographical scanning, three-dimensional scanning, laser tracking, tool tracking, and others. A laser mapping exposure frame as discussed herein may include topographical data for a scene, dimensions between objects or structures within a scene, dimensions or distances for tools or objects within a scene, and so forth.

[0067] Laser mapping generally includes the controlled deflection of laser beams. Within the field of three-dimensional object scanning, laser mapping combines controlled steering of laser beams with a laser rangefinder. By taking a distance measurement at every direction, the laser rangefinder can rapidly capture the surface shape of objects, tools, and landscapes. Construction of a full three-dimensional topology may include combining multiple surface models that are obtained from different viewing angles. Various measurement systems and methods exist in the art for applications in archaeology, geography, atmospheric physics, autonomous vehicles, and others. One such system includes light detection and ranging (LIDAR), which is a three-dimensional laser mapping system. LIDAR has been applied in navigation systems such as airplanes or satellites to determine position and orientation of a sensor in combination with other systems and sensors. LIDAR uses active sensors to illuminate an object and detect energy that is reflected off the object and back to a sensor.

[0068] As discussed herein, the term "laser mapping" includes laser tracking. Laser tracking, or the use of lasers for tool tracking, measures objects by determining the positions of optical targets held against those objects. Laser trackers can be accurate to the order of 0.025 mm over a distance of several meters. In an embodiment, an endoscopic imaging system pulses light for use in conjunction with a laser tracking system such that the position or tools within a scene can be tracked and measured. In such an embodiment, the endoscopic imaging system may pulse a laser tracking pattern on a tool, object, or other structure within a scene being imaged by the endoscopic imaging system. A target may be placed on the tool, object, or other structure within the scene. Measurements between the endoscopic imaging system and the target can be triggered and taken at selected points such that the position of the target (and the tool, object, or other structure to which the target is affixed) can be tracked by the endoscopic imaging system.

Pulsed Imaging

[0069] Some implementations of the disclosure include aspects of a combined sensor and system design that allows for high definition imaging with reduced pixel counts in a controlled illumination environment. This is accomplished with frame-by-frame pulsing of a single-color wavelength and switching or alternating each frame between a single, different color wavelength using a controlled light source in conjunction with high frame capture rates and a specially designed corresponding monochromatic sensor. Additionally, light pulsing patterns may be emitted for the generation of a specialty data such as hyperspectral, fluorescence, or laser mapping imaging data. The pixels may be color agnostic such that each pixel generates data for each pulse of electromagnetic radiation, including pulses for red, green, and blue visible light wavelengths along with other patterns used for specialty imaging.

[0070] A system of the disclosure is an endoscopic imaging system for use in a light deficient environment. The system includes an endoscope comprising an image sensor, wherein the image sensor is configured to sense reflected electromagnetic radiation for generating a plurality of exposure frames that can be combined to generate an RGB image frame with specialty data overlaid thereon. The system includes an emitter for emitting pulses of electromagnetic radiation. The system includes a controller (may alternatively be referred to as a "control circuit" in electronic communication with the image sensor and the emitter. The controller controls a duty cycle of the emitter in response to signals corresponding to a duty cycle of the emitter. The image sensor includes bidirectional pads that can send and receive information. The bidirectional pads of the image sensor operate in a frame period divided into three defined states, including a rolling readout state, a service line state, and a configuration state. The system includes an oscillator disposed in the controller and a frequency detector connected to the controller. The frequency detector controls a clock frequency of the image sensor in response to signals from the controller that correspond to the frequency of the oscillator.

The system is such that clock signal data is transmitted from the bidirectional pads of the image sensor to the controller during the service line phase and the configuration phase. The system is such that exposure frames are synchronized without the use of an input clock or a data transmission clock.

[0071] For the purposes of promoting an understanding of the principles in accordance with the disclosure, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications of the inventive features illustrated herein, and any additional applications of the principles of the disclosure as illustrated herein, which would normally occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the disclosure claimed.

[0072] Before the structure, systems and methods for producing an image in a light deficient environment are disclosed and described, it is to be understood that this disclosure is not limited to the particular structures, configurations, process steps, and materials disclosed herein as such structures, configurations, process steps, and materials may vary somewhat. It is also to be understood that the terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting since the scope of the disclosure will be limited only by the appended claims and equivalents thereof.

[0073] In describing and claiming the subject matter of the disclosure, the following terminology will be used in accordance with the definitions set out below.

[0074] It must be noted that, as used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise.

[0075] As used herein, the terms “comprising,” “including,” “containing,” “characterized by,” and grammatical equivalents thereof are inclusive or open-ended terms that do not exclude additional, unrecited elements or method steps.

[0076] As used herein, the phrase “consisting of” and grammatical equivalents thereof exclude any element or step not specified in the claim.

[0077] As used herein, the phrase “consisting essentially of” and grammatical equivalents thereof limit the scope of a claim to the specified materials or steps and those that do not materially affect the basic and novel characteristic or characteristics of the claimed disclosure.

[0078] As used herein, the term “proximal” shall refer broadly to the concept of a portion nearest an origin.

[0079] As used herein, the term “distal” shall generally refer to the opposite of proximal, and thus to the concept of a portion farther from an origin, or a furthest portion, depending upon the context.

[0080] As used herein, color sensors or multi spectrum sensors are those sensors known to have a color filter array (CFA) thereon to filter the incoming electromagnetic radiation into its separate components. In the visual range of the electromagnetic spectrum, such a CFA may be built on a Bayer pattern or modification thereon to separate green, red and blue spectrum components of the light.

[0081] As used herein, monochromatic sensor refers to an unfiltered imaging sensor. Since the pixels are color agnostic, the effective spatial resolution is appreciably higher than for their color (typically Bayer-pattern filtered) counterparts in conventional single-sensor cameras. Monochromatic sensors may also have higher quantum efficiency because fewer incident photons are wasted between individual pixels.

[0082] As used herein, an emitter is a device that is capable of generating and emitting electromagnetic pulses. Various embodiments of emitters may be configured to emit pulses and have very specific frequencies or ranges of

frequencies from within the entire electromagnetic spectrum. Pulses may comprise wavelengths from the visible and non-visible ranges. An emitter may be cycled on and off to produce a pulse or may produce a pulse with a shutter mechanism. An emitter may have variable power output levels or may be controlled with a secondary device such as an aperture or filter. An emitter may emit broad spectrum or full spectrum electromagnetic radiation that may produce pulses through color filtering or shuttering. An emitter may comprise a plurality of electromagnetic sources that act individually or in concert.

[0083] It should be noted that as used herein the term "light" is both a particle and a wavelength and is intended to denote electromagnetic radiation that is detectable by a pixel array 122 and may include wavelengths from the visible and non-visible spectrums of electromagnetic radiation. The term "partition" is used herein to mean a pre-determined range of wavelengths of the electromagnetic spectrum that is less than the entire spectrum, or in other words, wavelengths that make up some portion of the electromagnetic spectrum. As used herein, an emitter is a light source that may be controllable as to the portion of the electromagnetic spectrum that is emitted or that may operate as to the physics of its components, the intensity of the emissions, or the duration of the emission, or all the above. An emitter may emit light in any dithered, diffused, or collimated emission and may be controlled digitally or through analog methods or systems. As used herein, an electromagnetic emitter is a source of a burst of electromagnetic energy and includes light sources, such as lasers, LEDs, incandescent light, or any light source that can be digitally controlled.

[0084] Referring now to the figures, FIG. 1 illustrates a schematic diagram of a system 100 for sequential pulsed imaging in a light deficient environment. The system 100 can be deployed to generate an RGB image with specialty data overlaid on the RGB image. The system 100 includes an emitter 102 and a pixel array 122. The emitter 102 pulses a partition of electromagnetic radiation in the light deficient environment 112 and the pixel array 122 senses instances of reflected electromagnetic radiation. The emitter 102 and the pixel array 122 work in sequence such that one or more pulses of a partition of electromagnetic radiation results in image data sensed by the pixel array 122.

[0085] It should be noted that as used herein the term "light" is both a particle and a wavelength and is intended to denote electromagnetic radiation that is detectable by a pixel array 122 and may include wavelengths from the visible and non-visible spectrums of electromagnetic radiation. The term "partition" is used herein to mean a pre-determined range of wavelengths of the electromagnetic spectrum that is less than the entire spectrum, or in other words, wavelengths that make up some portion of the electromagnetic spectrum. As used herein, an emitter is a light source that may be controllable as to the portion of the electromagnetic spectrum that is emitted or that may operate as to the physics of its components, the intensity of the emissions, or the duration of the emission, or all the above. An emitter may emit light in any dithered, diffused, or collimated emission and may be controlled digitally or through analog methods or systems. As used herein, an electromagnetic emitter is a source of a burst of electromagnetic energy and includes light sources, such as lasers, LEDs, incandescent light, or any light source that can be digitally controlled.

[0086] A pixel array 122 of an image sensor may be paired with the emitter 102 electronically, such that the emitter 102 and the pixel array 122 are synced during operation for both receiving the emissions and for the adjustments made within the system. The emitter 102 may be tuned to emit electromagnetic radiation in the form of a laser, which may be pulsed to illuminate a light deficient environment 112. The emitter 102 may pulse at an interval that corresponds to the operation and functionality of the pixel array 122. The emitter 102 may pulse light in a plurality of electromagnetic partitions such that the pixel array receives electromagnetic energy and produces a dataset that corresponds in time with each specific electromagnetic partition. For example, FIG. 1 illustrates an implementation wherein the emitter 102 emits

four different partitions of electromagnetic radiation, including red 104, green 106, blue 108 wavelengths, and a specialty 110 emission. The specialty 110 emission may include an excitation wavelength for fluorescing a reagent, a hyperspectral partition of electromagnetic radiation, and/or a laser mapping pattern. The specialty 110 emission may include multiple separate emissions that are separate and independent from one another. The specialty 110 emission may include a combination of an excitation wavelength for fluorescing a reagent and a laser mapping pattern, wherein the emissions are separate and independent from one another. The data resulting from the separate emissions can be analyzed in tandem to identify a critical structure within a scene based on the fluorescence imaging data, and further to identify the dimensions or positioning of the critical structure based on the laser mapping data in combination with the fluorescence imaging data. The specialty 110 emission may include a combination of a hyperspectral band of electromagnetic radiation and a laser mapping pattern, wherein the emissions are separate and independent from one another. The data resulting from the separate emissions can be analyzed in tandem to identify a critical structure within a scene based on the hyperspectral imaging data, and further to identify the dimensions or positioning of the critical structure based on the laser mapping data in combination with the hyperspectral imaging data. In an embodiment, the specialty 110 emission includes any desirable combination of emissions that may be combined with the data resulting from the pulsed red 104, pulsed green 106, and pulsed blue 108 emissions. The specialty 110 emissions may be dispersed within a pulsing pattern such that the different types of specialty 110 emissions are not pulsed as frequently as the pulsed red 104, pulsed green 106, and pulsed blue 108 emissions.

[0087] In an alternative embodiment not illustrated in FIG. 1, the pulsed emissions of light include a luminance ("Y") emission, a red chrominance ("Cr") emission, and a blue chrominance ("Cb") emission in place of the pulsed red 104, pulsed green 106, and pulsed blue 108 emissions. In an embodiment, the controller or the emitter 102 modules the pulses of electromagnetic radiation to provide luminance and/or chrominance information according to color transformation coefficients that convert light energy from red, green, and blue light energy spaces to luminance, red chrominance, and blue chrominance light energy space. The pulsed emissions of light may further include modulated blue chrominance ("λY+Cb") pulses and/or modulated red chrominance ("δY+Cr") pulses.

[0088] The light deficient environment 112 includes structures, tissues, and other elements that reflect a combination of red 114, green 116, and/or blue 118 light. A structure that is perceived as being red 114 will reflect back pulsed red 104 light. The reflection off the red structure results in sensed red 105 by the pixel array 122 following the pulsed red 104 emission. The data sensed by the pixel array 122 results in a red exposure frame. A structure that is perceived as being green 116 will reflect back pulsed green 106 light. The reflection off the green structure results in sensed green 107 by the pixel array 122 following the pulsed green 106 emission. The data sensed by the pixel array 122 results in a green exposure frame. A structure that is perceived as being blue 118 will reflect back pulsed blue 108 light. The reflection off the blue structure results in sensed blue 109 by the pixel array 122 following the pulsed blue 108 emission. The data sensed by the pixel array 122 results in a blue exposure frame.

[0089] When a structure is a combination of colors, the structure will reflect back a combination of the pulsed red 104, pulsed green 106, and/or pulsed blue 108 emissions. For example, a structure that is perceived as being purple will reflect back light from the pulsed red 104 and pulsed blue 108 emissions. The resulting data sensed by the pixel array 122 will indicate that light was reflected in the same region following the pulsed red 104 and pulsed blue 108 emissions. When the resultant red exposure frame and blue exposure frames are combined to form the RGB image frame, the RGB image frame will indicate that the structure is purple.

[0090] In an embodiment where the light deficient environment 112 includes a fluorescent reagent or dye or includes one or more fluorescent structures, tissues, or other elements, the pulsing scheme may include the emission of a certain fluorescence excitation wavelength. The certain fluorescence excitation wavelength may be selected to fluoresce a known fluorescent reagent, dye, or other structure. The fluorescent structure will be sensitive to the fluorescence excitation wavelength and will emit a fluorescence relaxation wavelength. The fluorescence relaxation wavelength will be sensed by the pixel array 122 following the emission of the fluorescence excitation wavelength. The data sensed by the pixel array 122 results in a fluorescence exposure frame. The fluorescence exposure frame may be combined with multiple other exposure frames to form an image frame. The data in the fluorescence exposure frame may be overlaid on an RGB image frame that includes data from a red exposure frame, a green exposure frame, and a blue exposure frame.

[0091] In an embodiment where the light deficient environment 112 includes structures, tissues, or other materials that emit a spectral response to certain partitions of the electromagnetic spectrum, the pulsing scheme may include the emission of a hyperspectral partition of electromagnetic radiation for the purpose of eliciting the spectral response from the structures, tissues, or other materials present in the light deficient environment 112. The spectral response includes the emission or reflection of certain wavelengths of electromagnetic radiation. The spectral response can be sensed by the pixel array 122 and result in a hyperspectral exposure frame. The hyperspectral exposure frame may be combined with multiple other exposure frames to form an image frame. The data in the hyperspectral exposure frame may be overlaid on an RGB image frame that includes data from a red exposure frame, a green exposure frame, and a blue exposure frame.

[0092] In an embodiment, the pulsing scheme includes the emission of a laser mapping or tool tracking pattern. The reflected electromagnetic radiation sensed by the pixel array 122 following the emission of the laser mapping or tool tracking pattern results in a laser mapping exposure frame. The data in the laser mapping exposure frame may be provided to a corresponding system to identify, for example, distances between tools present in the light deficient environment 112, a three-dimensional surface topology of a scene in the light deficient environment 112, distances, dimensions, or positions of structures or objects within the scene, and so forth. This data may be overlaid on an RGB image frame or otherwise provided to a user of the system.

[0093] The emitter 102 may be a laser emitter that is capable of emitting pulsed red 104 light for generating sensed red 105 data for identifying red 114 elements within the light deficient environment 112. The emitter 102 is further capable of emitting pulsed green 106 light for generating sensed green 107 data for identifying green 116 elements within the light deficient environment. The emitter 102 is further capable of emitting pulsed blue 108 light for generating sensed blue 109 data for identifying blue 118 elements within the light deficient environment. The emitter 102 is further capable of emitting a specialty 110 emission for mapping the topology 120 of a scene within the light deficient environment 112. The emitter 102 is capable of emitting the pulsed red 104, pulsed green 106, pulsed blue 108, and pulsed specialty 110 emissions in any desired sequence.

[0094] The pixel array 122 senses reflected electromagnetic radiation. Each of the sensed red 105, the sensed green 107, the sensed blue 109, and the sensed specialty 111 data can be referred to as an "exposure frame." The sensed specialty 111 may result in multiple separate exposure frames that are separate and independent from one another. For example, the sensed specialty 111 may result in a fluorescence exposure frame, a hyperspectral exposure frame, and/or a laser mapping exposure frame comprising laser mapping data. Each exposure frame is assigned a specific color or

wavelength partition, wherein the assignment is based on the timing of the pulsed color or wavelength partition from the emitter 102. The exposure frame in combination with the assigned specific color or wavelength partition may be referred to as a dataset. Even though the pixels 122 are not color-dedicated, they can be assigned a color for any given dataset based on a priori information about the emitter.

[0095] For example, during operation, after pulsed red 104 light is pulsed in the light deficient environment 112, the pixel array 122 senses reflected electromagnetic radiation. The reflected electromagnetic radiation results in an exposure frame, and the exposure frame is catalogued as sensed red 105 data because it corresponds in time with the pulsed red 104 light. The exposure frame in combination with an indication that it corresponds in time with the pulsed red 104 light is the "dataset." This is repeated for each partition of electromagnetic radiation emitted by the emitter 102. The data created by the pixel array 122 includes the sensed red 105 exposure frame identifying red 114 components in the light deficient environment and corresponding in time with the pulsed red 104 light. The data further includes the sensed green 107 exposure frame identifying green 116 components in the light deficient environment and corresponding in time with the pulsed green 106 light. The data further includes the sensed blue 109 exposure frame identifying blue 118 components in the light deficient environment and corresponding in time with the pulsed blue 108 light. The data further includes the sensed specialty 111 exposure frame identifying the topology 120 and corresponding in time with the specialty 110 emission.

[0096] In one embodiment, three datasets representing RED, GREEN and BLUE electromagnetic pulses are combined to form a single image frame. Thus, the information in a red exposure frame, a green exposure frame, and a blue exposure frame are combined to form a single RGB image frame. One or more additional datasets representing other wavelength partitions may be overlaid on the single RGB image frame. The one or more additional datasets may represent, for example, the laser mapping data, fluorescence imaging data, and/or hyperspectral imaging data.

[0097] It will be appreciated that the disclosure is not limited to any particular color combination or any particular electromagnetic partition, and that any color combination or any electromagnetic partition may be used in place of RED, GREEN and BLUE, such as Cyan, Magenta and Yellow; Ultraviolet; infrared; any combination of the foregoing, or any other color combination, including all visible and non-visible wavelengths, without departing from the scope of the disclosure. In the figure, the light deficient environment 112 to be imaged includes red 114, green 116, and blue 118 portions, and further includes a topology 120 that can be sensed and mapped into a three-dimensional rendering. As illustrated in the figure, the reflected light from the electromagnetic pulses only contains the data for the portion of the object having the specific color that corresponds to the pulsed color partition. Those separate color (or color interval) datasets can then be used to reconstruct the image by combining the datasets at 126. The information in each of the multiple exposure frames (*i.e.*, the multiple datasets) may be combined by a controller 124, a control unit, a camera control unit, the image sensor, an image signal processing pipeline, or some other computing resource that is configurable to process the multiple exposure frames and combine the datasets at 126. The datasets may be combined to generate the single image frame within the endoscope unit itself or offsite by some other processing resource.

[0098] FIG. 2 is a system 200 for providing illumination to a light deficient environment, such as for endoscopic imaging. The system 200 may be used in combination with any of the systems, methods, or devices disclosed herein. The system 200 includes an emitter 202, a controller 204, a jumper waveguide 206, a waveguide connector 208, a lumen waveguide 210, a lumen 212, and an image sensor 214 with accompanying optical components (such as a lens). The emitter 202 (may be generically referred to as a "light source") generates light that travels through the jumper waveguide

206 and the lumen waveguide 210 to illuminate a scene at a distal end of the lumen 212. The emitter 202 may be used to emit any wavelength of electromagnetic energy including visible wavelengths, infrared, ultraviolet, hyperspectral, fluorescence excitation, or other wavelengths. The lumen 212 may be inserted into a patient's body for imaging, such as during a procedure or examination. The light is output as illustrated by dashed lines 216. A scene illuminated by the light may be captured using the image sensor 214 and displayed for a doctor or some other medical personnel. The controller 204 may provide control signals to the emitter 202 to control when illumination is provided to a scene. In one embodiment, the emitter 202 and controller 204 are located within a camera control unit (CCU) or external console to which an endoscope is connected. If the image sensor 214 includes a CMOS sensor, light may be periodically provided to the scene in a series of illumination pulses between readout periods of the image sensor 214 during what is known as a blanking period. Thus, the light may be pulsed in a controlled manner to avoid overlapping into readout periods of the image pixels in a pixel array of the image sensor 214.

[0099] In one embodiment, the lumen waveguide 210 includes one or more optical fibers. The optical fibers may be made of a low-cost material, such as plastic to allow for disposal of the lumen waveguide 210 and/or other portions of an endoscope. In one embodiment, the lumen waveguide 210 is a single glass fiber having a diameter of 500 microns. The jumper waveguide 206 may be permanently attached to the emitter 202. For example, a jumper waveguide 206 may receive light from an emitter within the emitter 202 and provide that light to the lumen waveguide 210 at the location of the connector 208. In one embodiment, the jumper waveguide 106 includes one or more glass fibers. The jumper waveguide may include any other type of waveguide for guiding light to the lumen waveguide 210. The connector 208 may selectively couple the jumper waveguide 206 to the lumen waveguide 210 and allow light within the jumper waveguide 206 to pass to the lumen waveguide 210. In one embodiment, the lumen waveguide 210 is directly coupled to a light source without any intervening jumper waveguide 206.

[0100] The image sensor 214 includes a pixel array. In an embodiment, the image sensor 214 includes two or more pixel arrays for generating a three-dimensional image. The image sensor 214 may constitute two more image sensors that each have an independent pixel array and can operate independent of one another. The pixel array of the image sensor 214 includes active pixels and optical black ("OB") or optically blind pixels. The active pixels may be clear "color agnostic" pixels that are capable of sensing imaging data for any wavelength of electromagnetic radiation. The optical black pixels are read during a blanking period of the pixel array when the pixel array is "reset" or calibrated. In an embodiment, light is pulsed during the blanking period of the pixel array when the optical black pixels are being read. After the optical black pixels have been read, the active pixels are read during a readout period of the pixel array. The active pixels may be charged by the electromagnetic radiation that is pulsed during the blanking period such that the active pixels are ready to be read by the image sensor during the readout period of the pixel array.

[0101] FIG. 2A is a schematic diagram of complementary system hardware such as a special purpose or general-purpose computer. Implementations within the scope of the present disclosure may also include physical and other non-transitory computer readable media for carrying or storing computer executable instructions and/or data structures. Such computer readable media can be any available media that can be accessed by a general purpose or special purpose computer system. Computer readable media that stores computer executable instructions are computer storage media (devices). Computer readable media that carry computer executable instructions are transmission media. Thus, by way of example, and not limitation, implementations of the disclosure can comprise at least two distinctly different kinds of computer readable media: computer storage media (devices) and transmission media.

[0102] Computer storage media (devices) includes RAM, ROM, EEPROM, CD-ROM, solid state drives ("SSDs") (e.g., based on RAM), Flash memory, phase-change memory ("PCM"), other types of memory, other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store desired program code means in the form of computer executable instructions or data structures and which can be accessed by a general purpose or special purpose computer.

[0103] A "network" is defined as one or more data links that enable the transport of electronic data between computer systems and/or modules and/or other electronic devices. In an implementation, a sensor and camera control unit may be networked to communicate with each other, and other components, connected over the network to which they are connected. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a computer, the computer properly views the connection as a transmission medium. Transmissions media can include a network and/or data links, which can be used to carry desired program code means in the form of computer executable instructions or data structures and which can be accessed by a general purpose or special purpose computer. Combinations of the above should also be included within the scope of computer readable media.

[0104] Further, upon reaching various computer system components, program code means in the form of computer executable instructions or data structures that can be transferred automatically from transmission media to computer storage media (devices) (or vice versa). For example, computer executable instructions or data structures received over a network or data link can be buffered in RAM within a network interface module (e.g., a "NIC"), and then eventually transferred to computer system RAM and/or to less volatile computer storage media (devices) at a computer system. RAM can also include solid state drives (SSDs or PCIx based real time memory tiered storage, such as FusionIO). Thus, it should be understood that computer storage media (devices) can be included in computer system components that also (or even primarily) utilize transmission media.

[0105] Computer executable instructions comprise, for example, instructions and data which, when executed by one or more processors, cause a general-purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. The computer executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, or even source code. Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the described features or acts described above. Rather, the described features and acts are disclosed as example forms of implementing the claims.

[0106] Those skilled in the art will appreciate that the disclosure may be practiced in network computing environments with many types of computer system configurations, including, personal computers, desktop computers, laptop computers, message processors, control units, camera control units, hand-held devices, hand pieces, multi-processor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, mobile telephones, PDAs, tablets, pagers, routers, switches, various storage devices, and the like. It should be noted that any of the above-mentioned computing devices may be provided by or located within a brick and mortar location. The disclosure may also be practiced in distributed system environments where local and remote computer systems, which are linked (either by hardwired data links, wireless data links, or by a combination of hardwired and wireless data links) through a network, both perform tasks. In a distributed system environment, program modules may be located in both local and remote memory storage devices.

[0107] Further, where appropriate, functions described herein can be performed in one or more of: hardware, software, firmware, digital components, or analog components. For example, one or more application specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) can be programmed to carry out one or more of the systems and procedures described herein. Certain terms are used throughout the following description and Claims to refer to particular system components. As one skilled in the art will appreciate, components may be referred to by different names. This document does not intend to distinguish between components that differ in name, but not function.

[0108] FIG. 2A is a block diagram illustrating an example computing device 250. Computing device 250 may be used to perform various procedures, such as those discussed herein. Computing device 250 can function as a server, a client, or any other computing entity. Computing device 250 can perform various monitoring functions as discussed herein, and can execute one or more application programs, such as the application programs described herein. Computing device 250 can be any of a wide variety of computing devices, such as a desktop computer, a notebook computer, a server computer, a handheld computer, camera control unit, tablet computer and the like.

[0109] Computing device 250 includes one or more processor(s) 252, one or more memory device(s) 254, one or more interface(s) 256, one or more mass storage device(s) 258, one or more Input/Output (I/O) device(s) 260, and a display device 280 all of which are coupled to a bus 262. Processor(s) 252 include one or more processors or controllers that execute instructions stored in memory device(s) 254 and/or mass storage device(s) 258. Processor(s) 252 may also include various types of computer readable media, such as cache memory.

[0110] Memory device(s) 254 include various computer readable media, such as volatile memory (e.g., random access memory (RAM) 264) and/or nonvolatile memory (e.g., read-only memory (ROM) 266). Memory device(s) 254 may also include rewritable ROM, such as Flash memory.

[0111] Mass storage device(s) 258 include various computer readable media, such as magnetic tapes, magnetic disks, optical disks, solid-state memory (e.g., Flash memory), and so forth. As shown in FIG. 2, a particular mass storage device is a hard disk drive 274. Various drives may also be included in mass storage device(s) 258 to enable reading from and/or writing to the various computer readable media. Mass storage device(s) 258 include removable media 276 and/or non-removable media.

[0112] I/O device(s) 260 include various devices that allow data and/or other information to be input to or retrieved from computing device 250. Example I/O device(s) 260 include digital imaging devices, electromagnetic sensors and emitters, cursor control devices, keyboards, keypads, microphones, monitors or other display devices, speakers, printers, network interface cards, modems, lenses, CCDs or other image capture devices, and the like.

[0113] Display device 280 includes any type of device capable of displaying information to one or more users of computing device 250. Examples of display device 280 include a monitor, display terminal, video projection device, and the like.

[0114] Interface(s) 256 include various interfaces that allow computing device 250 to interact with other systems, devices, or computing environments. Example interface(s) 256 may include any number of different network interfaces 270, such as interfaces to local area networks (LANs), wide area networks (WANs), wireless networks, and the Internet. Other interface(s) include user interface 268 and peripheral device interface 272. The interface(s) 256 may also include one or more user interface elements 268. The interface(s) 256 may also include one or more peripheral interfaces such as interfaces for printers, pointing devices (mice, track pad, etc.), keyboards, and the like.

[0115] Bus 262 allows processor(s) 252, memory device(s) 254, interface(s) 256, mass storage device(s) 258, and I/O device(s) 260 to communicate with one another, as well as other devices or components coupled to bus 262. Bus 262 represents one or more of several types of bus structures, such as a system bus, PCI bus, IEEE 1394 bus, USB bus, and so forth.

[0116] For purposes of illustration, programs and other executable program components are shown herein as discrete blocks, although it is understood that such programs and components may reside at various times in different storage components of computing device 250 and are executed by processor(s) 252. Alternatively, the systems and procedures described herein can be implemented in hardware, or a combination of hardware, software, and/or firmware. For example, one or more application specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) can be programmed to carry out one or more of the systems and procedures described herein.

[0117] FIG. 3A illustrates the operational cycles of a sensor used in rolling readout mode or during the sensor readout 300. The frame readout may start at and may be represented by vertical line 310. The read-out period is represented by the diagonal or slanted line 302. The active pixels of the pixel array of the image sensor may be read out on a row by row basis, the top of the downwards slanted edge being the sensor top row 312 and the bottom of the downwards slanted edge being the sensor bottom row 314. The time between the last row readout and the next readout cycle may be called the blanking period 316. It should be noted that some of the sensor pixel rows might be covered with a light shield (e.g., a metal coating or any other substantially black layer of another material type). These covered pixel rows may be referred to as optical black rows 318 and 320. Optical black rows 318 and 320 may be used as input for correction algorithms. As shown in FIG. 3A, these optical black rows 318 and 320 may be located on the top of the pixel array or at the bottom of the pixel array or at the top and the bottom of the pixel array.

[0118] FIG. 3B illustrates a process of controlling the amount of electromagnetic radiation, e.g., light, that is exposed to a pixel, thereby integrated or accumulated by the pixel. It will be appreciated that photons are elementary particles of electromagnetic radiation. Photons are integrated, absorbed, or accumulated by each pixel and converted into an electrical charge or current. An electronic shutter or rolling shutter (shown by dashed line 322) may be used to start the integration time by resetting the pixel. The light will then integrate until the next readout phase. The position of the electronic shutter 322 can be moved between two readout cycles 302 to control the pixel saturation for a given amount of light. It should be noted that this technique allows for a constant integration time between two different lines but introduces a delay when moving from top to bottom rows.

[0119] FIG. 3C illustrates the case where the electronic shutter 322 has been removed. In this configuration, the integration of the incoming light may start during readout 302 and may end at the next readout cycle 302, which also defines the start of the next integration.

[0120] FIG. 3D shows a configuration without an electronic shutter 322, but with a controlled and pulsed light 330 during the blanking period 316. This ensures that all rows see the same light issued from the same light pulse 330. In other words, each row will start its integration in a dark environment, which may be at the optical black back row 320 of read out frame (m) for a maximum light pulse width, and will then receive a light strobe and will end its integration in a dark environment, which may be at the optical black front row 318 of the next succeeding read out frame (m+1) for a maximum light pulse width. In the FIG. 3D example, the image generated from the light pulse will be solely available during frame (m+1) readout without any interference with frames (m) and (m+2). It should be noted that the condition to have a light pulse to be read out only in one frame and not interfere with neighboring frames is to have the given light

pulse firing during the blanking period 316. Because the optical black rows 318, 320 are insensitive to light, the optical black back rows 320 time of frame (m) and the optical black front rows 318 time of frame (m+1) can be added to the blanking period 316 to determine the maximum range of the firing time of the light pulse 330.

[0121] As illustrated in the FIG. 3A, a sensor may be cycled many times to receive data for each pulsed color or wavelength (e.g., Red, Green, Blue, or other wavelength on the electromagnetic spectrum). Each cycle may be timed. In an embodiment, the cycles may be timed to operate within an interval of 16.67ms. In another embodiment, the cycles may be timed to operate within an interval of 8.3ms. It will be appreciated that other timing intervals are contemplated by the disclosure and are intended to fall within the scope of this disclosure.

[0122] FIG. 4A graphically illustrates the operation of an embodiment of an electromagnetic emitter. An emitter may be timed to correspond with the cycles of a sensor, such that electromagnetic radiation is emitted within the sensor operation cycle and/or during a portion of the sensor operation cycle. FIG. 4A illustrates Pulse 1 at 402, Pulse 2 at 404, and Pulse 3 at 406. In an embodiment, the emitter may pulse during the readout period 302 of the sensor operation cycle. In an embodiment, the emitter may pulse during the blanking portion 316 of the sensor operation cycle. In an embodiment, the emitter may pulse for a duration that is during portions of two or more sensor operational cycles. In an embodiment, the emitter may begin a pulse during the blanking portion 316, or during the optical black portion 320 of the readout period 302, and end the pulse during the readout period 302, or during the optical black portion 318 of the readout period 302 of the next succeeding cycle. It will be understood that any combination of the above is intended to fall within the scope of this disclosure as long as the pulse of the emitter and the cycle of the sensor correspond.

[0123] FIG. 4B graphically represents varying the duration and magnitude of the emitted electromagnetic pulse (e.g., Pulse 1 at 412, Pulse 2 at 414, and Pulse 3 at 416) to control exposure. An emitter having a fixed output magnitude may be pulsed during any of the cycles noted above in relation to FIGS. 3D and 4A for an interval to provide the needed electromagnetic energy to the pixel array. An emitter having a fixed output magnitude may be pulsed at a longer interval of time, thereby providing more electromagnetic energy to the pixels or the emitter may be pulsed at a shorter interval of time, thereby providing less electromagnetic energy. Whether a longer or shorter interval time is needed depends upon the operational conditions.

[0124] In contrast to adjusting the interval of time the emitter pulses a fixed output magnitude, the magnitude of the emission itself may be increased to provide more electromagnetic energy to the pixels. Similarly, decreasing the magnitude of the pulse provides less electromagnetic energy to the pixels. It should be noted that an embodiment of the system may have the ability to adjust both magnitude and duration concurrently, if desired. Additionally, the sensor may be adjusted to increase its sensitivity and duration as desired for optimal image quality. FIG. 4B illustrates varying the magnitude and duration of the pulses. In the illustration, Pulse 1 at 412 has a higher magnitude or intensity than either Pulse 2 at 414 or Pulse 3 at 416. Additionally, Pulse 1 at 412 has a shorter duration than Pulse 2 at 414 or Pulse 3 at 416, such that the electromagnetic energy provided by the pulse is illustrated by the area under the pulse shown in the illustration. In the illustration, Pulse 2 at 414 has a relatively low magnitude or intensity and a longer duration when compared to either Pulse 1 at 412 or Pulse 3 at 416. Finally, in the illustration, Pulse 3 at 416 has an intermediate magnitude or intensity and duration, when compared to Pulse 1 at 412 and Pulse 2 at 414.

[0125] FIG. 5 is a graphical representation of an embodiment of the disclosure combining the operational cycles, the electromagnetic emitter, and the emitted electromagnetic pulses of FIGS. 3A-3D and 4A to demonstrate the imaging system during operation in accordance with the principles and teachings of the disclosure. As can be seen in the figure,

the electromagnetic emitter pulses the emissions primarily during the blanking period 316 of the image sensor such that the pixels will be charged and ready to read during the readout period 302 of the image sensor cycle. The dashed lines in FIG. 5 represent the pulses of electromagnetic radiation (from FIG. 4A). The pulses of electromagnetic radiation are primarily emitted during the blanking period 316 of the image sensor but may overlap with the readout period 302 of the image sensor.

[0126] An exposure frame includes the data read by the pixel array of the image sensor during a readout period 302. The exposure frame may be combined with an indication of what type of pulse was emitted by the emitter prior to the readout period 302. The combination of the exposure frame and the indication of the pulse type may be referred to as a dataset. Multiple exposure frames may be combined to generate a black-and-white or RGB color image. Additionally, hyperspectral, fluorescence, and/or laser mapping imaging data may be overlaid on a black-and-white or RGB image.

[0127] In an embodiment, an RGB image frame is generated based on three exposure frames, including a red exposure frame generated by the image sensor subsequent to a red emission, a green exposure frame generated by the image sensor subsequent to a green emission, and a blue exposure frame generated by the image sensor subsequent to a blue emission. Fluorescence imaging data may be overlaid on the RGB image frame. The fluorescence imaging data may be drawn from one or more fluorescence exposure frames. A fluorescence exposure frame includes data generated by the image sensor during the readout period 302 subsequent to emission of an excitation wavelength of electromagnetic radiation for exciting a fluorescent reagent. The data sensed by the pixel array subsequent to the excitation of the fluorescent reagent may be the relaxation wavelength emitted by the fluorescent reagent. The fluorescence exposure frame may include multiple fluorescence exposure frames that are each generated by the image sensor subsequent to a different type of fluorescence excitation emission. In an embodiment, the fluorescence exposure frame includes multiple fluorescence exposure frames, including a first fluorescence exposure frame generated by the image sensor subsequent to an emission of electromagnetic radiation with a wavelength from about 770 nm to about 790 and a second fluorescence exposure frame generated by the image sensor subsequent to an emission of electromagnetic radiation with a wavelength from about 795 nm to about 815 nm. The fluorescence exposure frame may include further additional fluorescence exposure frames that are generated by the image sensor subsequent to other fluorescence excitation emissions of light as needed based on the imaging application.

[0128] In an embodiment, an exposure frame is the data sensed by the pixel array during the readout period 302 that occurs subsequent to a blanking period 316. The emission of electromagnetic radiation is emitted during the blanking period 316. In an embodiment, a portion of the emission of electromagnetic radiation overlaps the readout period 316. The blanking period 316 occurs when optical black pixels of the pixel array are being read and the readout period 302 occurs when active pixels of the pixel array are being read. The blanking period 316 may overlap the readout period 302.

[0129] FIGS. 6A and 6B illustrate processes for recording an image frame. Multiple image frames may be strung together to generate a video stream. A single image frame may include data from multiple exposure frames, wherein an exposure frame is the data sensed by a pixel array subsequent to an emission of electromagnetic radiation. FIG. 6A illustrates a traditional process that is typically implemented with a color image sensor having a color filter array (CFA) for filtering out certain wavelengths of light per pixel. FIG. 6B is a process that is disclosed herein and can be

implemented with a monochromatic "color agnostic" image sensor that is receptive to all wavelengths of electromagnetic radiation.

[0130] The process illustrated in FIG. 6A occurs from time t(0) to time t(1). The process begins with a white light emission 602 and sensing white light 604. The image is processed and displayed at 606 based on the sensing at 604.

[0131] The process illustrated in FIG. 6B occurs from time t(0) to time t(1). The process begins with an emission of green light 612 and sensing reflected electromagnetic radiation 614 subsequent to the emission of green light 612. The process continues with an emission of red light 616 and sensing reflected electromagnetic radiation 618 subsequent to the emission of red light 616. The process continues with an emission of blue light 620 and sensing reflected electromagnetic radiation 622 subsequent to the emission of blue light 620. The process continues with one or more emissions of a specialty 624 emission and sensing reflected electromagnetic energy 626 subsequent to each of the one or more emissions of the specialty 624 emission. The specialty emission may include one or more separate emissions such as an excitation wavelength of a fluorescent reagent, a hyperspectral emission, and/or a laser mapping emission. Each of the separate multiple specialty emissions may be independently sensed by the image sensor to generate separate and independent exposure frames. The image is processed and displayed at 628 based on each of the sensed reflected electromagnetic energy instances 614, 618, 622, and 626.

[0132] The process illustrated in FIG. 6B provides a higher resolution image and provides a means for generating an RGB image that further includes specialty data. When partitioned spectrums of light are used, (as in FIG. 6B) a sensor can be made sensitive to all wavelengths of electromagnetic energy. In the process illustrated in FIG. 6B, the monochromatic pixel array is instructed that it is sensing electromagnetic energy from a predetermined partition of the full spectrum of electromagnetic energy in each cycle. Therefore, to form an image the sensor need only be cycled with a plurality of differing partitions from within the full spectrum of light. The final image is assembled based on the multiple cycles. Because the image from each color partition frame cycle has a higher resolution (compared with a CFA pixel array), the resultant image created when the partitioned light frames are combined also has a higher resolution. In other words, because each and every pixel within the array (instead of, at most, every second pixel in a sensor with a CFA) is sensing the magnitudes of energy for a given pulse and a given scene, just fractions of time apart, a higher resolution image is created for each scene.

[0133] As can be seen graphically in the embodiments illustrated in FIGS. 6A and 6B between times t(0) and t(1), the sensor for the partitioned spectrum system in FIG. 6B has cycled at least four times for every one of the full spectrum system in FIG. 6A. In an embodiment, a display device (LCD panel) operates at 50-60 frames per second. In such an embodiment, the partitioned light system in FIG. 6B may operate at 200-240 frames per second to maintain the continuity and smoothness of the displayed video. In other embodiments, there may be different capture and display frame rates. Furthermore, the average capture rate could be any multiple of the display rate.

[0134] In an embodiment, it may be desired that not all partitions be represented equally within the system frame rate. In other words, not all light sources have to be pulsed with the same regularity so as to emphasize and de-emphasize aspects of the recorded scene as desired by the users. It should also be understood that non-visible and visible partitions of the electromagnetic spectrum may be pulsed together within a system with their respective data value being stitched into the video output as desired for display to a user.

[0135] An example embodiment may comprise a pulse cycle pattern as follows:

i. Green pulse;

ii. Red pulse;
iii. Blue pulse;
iv. Green pulse;
v. Red pulse;
vi. Blue pulse;
vii. Laser mapping pulsing scheme;
viii. Fluorescence excitation pulse;
ix. Hyperspectral pulse;
x. (Repeat)

[0136] A further example embodiment may comprise a pulse cycle pattern as follows:

i. Green pulse;
ii. Red pulse;
iii. Blue pulse;
iv. Fluorescence excitation pulse;
v. Hyperspectral pulse;
vi. Green pulse;
vii. Red pulse;
viii. Blue pulse;
ix. Fluorescence excitation pulse;
x. Hyperspectral pulse;
xi. Laser mapping pulsing scheme;
xii. (Repeat)

[0137] An embodiment may comprise a pulse cycle pattern as follows:

i. Luminance pulse;
ii. Red chrominance pulse;
iii. Luminance pulse;
iv. Blue chrominance pulse;
v. Hyperspectral pulse;
vi. Fluorescence excitation pulse;
vii. Laser mapping pulse;
viii. (Repeat)

[0138] An embodiment may comprise a pulse cycle pattern as follows:

i. Luminance pulse;
ii. Red chrominance pulse;
iii. Luminance pulse;
iv. Blue chrominance pulse;
v. Luminance pulse;
vi. Red chrominance pulse;
vii. Luminance pulse;

viii. Blue chrominance pulse;
ix. Hyperspectral pulse;
x. Fluorescence excitation pulse;
xi. Laser mapping pulse;
xii. (Repeat)

[0139] The pulsing pattern may be altered to suit the imaging objectives for a specific implementation. An example imaging objective is to obtain hyperspectral imaging data and fluorescence imaging data, and further to obtain laser mapping and/or tool tracking data that is based on analysis of the hyperspectral and/or fluorescence imaging data. In such an example, the laser mapping and/or tool tracking data may be analyzed for certain areas of a scene that have been highlighted by the hyperspectral and/or fluorescence imaging data. A further example imaging objective is to obtain hyperspectral imaging data or fluorescence imaging data, and further to obtain laser mapping and/or tool tracking data. A further example imaging objective is to obtain laser mapping and/or tool tracking data. A further example imaging objective is to obtain hyperspectral imaging data. A further example imaging objective is to obtain fluorescence imaging data. It should be appreciated that the imaging objective may be specialized depending on the reason for deploying the imaging system. Additionally, the imaging objective may change during a single imaging session, and the pulsing pattern may be altered to match the changing imaging objectives.

[0140] As can be seen in the example, a laser mapping partition may be pulsed at a rate differing from the rates of the other partition pulses. This may be done to emphasize a certain aspect of the scene, with the laser mapping data simply being overlaid with the other data in the video output to make the desired emphasis. It should be noted that the addition of a laser mapping partition on top of the RED, GREEN, and BLUE partitions does not necessarily require the serialized system to operate at four times the rate of a full spectrum non-serial system because every partition does not have to be represented equally in the pulse pattern. As seen in the embodiment, the addition of a partition pulse that is represented less in a pulse pattern (laser mapping in the above example), would result in an increase of less than 20% of the cycling speed of the sensor to accommodate the irregular partition sampling.

[0141] In various embodiments, the pulse cycle pattern may further include any of the following wavelengths in any suitable order. Such wavelengths may be particularly suited for exciting a fluorescent reagent to generate fluorescence imaging data by sensing the relaxation emission of the fluorescent reagent based on a fluorescent reagent relaxation emission:

i. 770 ± 20 nm;
ii. 770 ± 10 nm;
iii. 770 ± 5 nm;
iv. 790 ± 20 nm;
v. 790 ± 10 nm;
vi. 790 ± 5 nm;
vii. 795 ± 20 nm;
viii. 795 ± 10 nm;
ix. 795 ± 5 nm;
x. 815 ± 20 nm;

xi. 815 ± 10 nm;

xii. 815 ± 5 nm;

xiii. 770 nm to 790 nm; and/or

xiv. 795 nm to 815 nm.

[0142] In various embodiments, the pulse cycle may further include any of the following wavelengths in any suitable order. Such wavelengths may be particularly suited for generating hyperspectral imaging data:

i. 513 nm to 545 nm;

ii. 565 nm to 585 nm;

iii. 900 nm to 1000 nm;

iv. 513 ± 5 nm;

v. 513 ± 10 nm;

vi. 513 ± 20 nm;

vii. 513 ± 30 nm;

viii. 513 ± 35 nm;

ix. 545 ± 5 nm;

x. 545 ± 10 nm;

xi. 545 ± 20 nm;

xii. 545 ± 30 nm;

xiii. 545 ± 35 nm;

xiv. 565 ± 5 nm;

xv. 565 ± 10 nm;

xvi. 565 ± 20 nm;

xvii. 565 ± 30 nm;

xviii. 565 ± 35 nm;

xix. 585 ± 5 nm;

xx. 585 ± 10 nm;

xxi. 585 ± 20 nm;

xxii. 585 ± 30 nm;

xxiii. 585 ± 35 nm;

xxiv. 900 ± 5 nm;

xxv. 900 ± 10 nm;

xxvi. 900 ± 20 nm;

xxvii. 900 ± 30 nm;

xxviii. 900 ± 35 nm;

xxix. 1000 ± 5 nm;

xxx. 1000 ± 10 nm;

xxxi. 1000 ± 20 nm;

xxxii. 1000 ± 30 nm; or

xxxiii. 1000 ± 35 nm.

[0143] The partition cycles may be divided so as to accommodate or approximate various imaging and video standards. In an embodiment, the partition cycles may comprise pulses of electromagnetic energy in the Red, Green, and Blue spectrum as follows as illustrated best in FIGS. 7A-7D. In FIG. 7A, the different light intensities have been achieved by modulating the light pulse width or duration within the working range shown by the vertical grey dashed lines. In FIG. 7B, the different light intensities have been achieved by modulating the light power or the power of the electromagnetic emitter, which may be a laser or LED emitter, but keeping the pulse width or duration constant. FIG. 7C shows the case where both the light power and the light pulse width are being modulated, leading to greater flexibility. The partition cycles may use Cyan Magenta Yellow (CMY), infrared, ultraviolet, hyperspectral, and fluorescence using a non-visible pulse source mixed with visible pulse sources and any other color space required to produce an image or approximate a desired video standard that is currently known or yet to be developed. It should also be understood that a system may be able to switch between the color spaces on the fly to provide the desired image output quality.

[0144] In an embodiment using color spaces Green-Blue-Green-Red (as seen in FIG. 7D) it may be desirous to pulse the luminance components more often than the chrominance components because users are generally more sensitive to light magnitude differences than to light color differences. This principle can be exploited using a mono-chromatic sensor as illustrated in FIG. 7D. In FIG. 7D, green, which contains the most luminance information, may be pulsed more often or with more intensity in a (G-B-G-R-G-B-G-R…) scheme to obtain the luminance data. Such a configuration would create a video stream that has perceptively more detail, without creating and transmitting unperceivable data.

[0145] In an embodiment, duplicating the pulse of a weaker partition may be used to produce an output that has been adjusted for the weaker pulse. For example, blue laser light is considered weak relative to the sensitivity of silicon-based pixels and is difficult to produce in comparison to the red or green light, and therefore may be pulsed more often during a frame cycle to compensate for the weakness of the light. These additional pulses may be done serially over time or by using multiple lasers that simultaneously pulse to produce the desired compensation effect. It should be noted that by pulsing during a blanking period (time during which the sensor is not reading out the pixel array), the sensor is insensitive to differences/mismatches between lasers of the same kind and simply accumulates the light for the desired output. In another embodiment, the maximum light pulse range may be different from frame to frame. This is shown in FIG. 7E, where the light pulses are different from frame to frame. The sensor may be built to be able to program different blanking periods with a repeating pattern of two or three or four or n frames.

[0146] In FIG. 7E, four different light pulses are illustrated, and Pulse 1 may repeat for example after Pulse 4 and may have a pattern of four frames with different blanking periods. This technique can be used to place the most powerful partition on the smallest blanking period and therefore allow the weakest partition to have wider pulse on one of the next frames without the need of increasing the readout speed. The reconstructed frame can still have a regular pattern from frame to frame as it is constituted of many pulsed frames.

[0147] FIG. 8 illustrates a pixel array 800 of an image sensor. The pixel array 800 comprises a plurality of pixels arranged in a grid-like pattern. The pixels are depicted as discrete squares in FIGS. 8-14. The pixel array 800 is configured for sensing reflected electromagnetic radiation for generating an image frame based on a plurality of independent exposure frames. The image frame may comprise information from a luminance exposure frame, a blue chrominance exposure frame, and a red chrominance exposure frame, and may further include information from one or

more of a hyperspectral exposure frame, a fluorescence exposure frame, and/or a laser mapping exposure frame. In FIG. 8, the pixel array 800 is illustrated with four different configurations over time, including configurations for a first exposure frame 802, a second exposure frame 804, a third exposure frame 806, and a fourth exposure frame 808. The first exposure frame 802, the second exposure frame 804, the third exposure frame 806, and the fourth exposure frame 808 may be combined to generate a single YCbCr image frame. One or more additional exposure frames may be combined with or overlaid on the YCbCr image frame, including for example, a hyperspectral exposure frame, a fluorescence exposure frame, and/or a laser mapping or tool tracking exposure frame. In some instances, information from one or more of the hyperspectral exposure frame, the fluorescence exposure frame, and/or the laser mapping or tool tracking exposure frame is translated to numerical information, color overlays, or some other form, when combined with the RGB image frame.

[0148] When the pixel array 800 is configured for the first exposure frame 802, the pixels are operated to sense luminance ("Y") information. The pixel configuration for the first exposure frame 802 includes only luminance pixels 810. When the pixel array 800 is configured for the second exposure frame 804, the pixels are operated to sense blue chrominance ("Cb") information. The pixel configuration for the second exposure frame 804 includes only blue chrominance pixels 812. When the pixel array 800 is configured for the third exposure frame 806, the pixel are operated to sense luminance information again. The pixel configuration for the third exposure frame 806 includes only luminance pixels 810. When the pixel array 800 is configured for the fourth exposure frame 808, the pixels are operated to sense red chrominance ("Cr") information. The pixel configuration for the fourth exposure frame 808 includes only red chrominance pixels 814.

[0149] FIG. 9 illustrates a pixel array 900 of an image sensor similar to those illustrated in FIGS. 8 and 10-14. The image sensor is configured for generating a YCbCr image frame based on a plurality of independent exposure frames captured by the pixel array 900. The pixel array 900 is illustrated in four different configurations over time, including configurations for a first exposure frame 902, a second exposure frame 904, a third exposure frame 906, and a fourth exposure frame 908. The configuration of the pixels for the first exposure frame 902 includes luminance pixels 910. The configuration of the pixels for the second exposure frame 904 includes blue chrominance pixels 912 and red chrominance pixels 914 arranged in a checkerboard pattern. The configuration of the pixels for the third exposure frame 906 includes luminance pixels 910. The configuration of the pixels for the fourth exposure frame 908 includes blue chrominance pixels 912 and red chrominance pixels 914. In an embodiment, the pixel configurations for the second exposure frame 904 and the fourth exposure frame 908 sense modulated blue chrominance ("λY+Cb") and modulated red chrominance ("δY+Cr").

[0150] FIG. 10 illustrates a pixel array 1000 of an image sensor similar to those illustrated in FIGS. 8-9 and 11-14. The image sensor is configured for generating a YCbCr image frame based on a plurality of independent exposure frames captured by the pixel array 1000. The pixel array 1000 is illustrated with four different configurations over time, including configurations for a first exposure frame 1002, a second exposure frame 1004, a third exposure frame 1006, and a fourth exposure frame 1008. The data sensed by the pixel array 1000 for the multiple exposure frames 1002, 1004, 1006, 1008 can be combined to generate a single YCbCr image frame. The configuration of the pixels for the first exposure frame 1002 includes luminance short exposure pixels ("Y_S") 1016 and luminance long exposure pixels ("Y_L") 1018 arranged in a checkerboard pattern. The configuration of the pixels for the second exposure frame 1004 includes blue chrominance pixels 1012 and red chrominance pixels 1014. The configuration of the pixels for the third exposure

frame 1006 includes luminance long exposure pixels 1018 and luminance short exposure pixels 1016 arranged in a checkerboard pattern with an opposite configuration with respect to the arrangement for the first exposure frame 1002. The configuration of the pixels for the fourth exposure frame 1008 includes blue chrominance pixels 1012 and red chrominance pixels 1014.

[0151] FIG. 11 illustrates a pixel array 1100 of an image sensor similar to those illustrated in FIGS. 8-10 and 12-14. The image sensor is configured for generating an RGB image frame based on a plurality of independent exposure frames captured by the pixel array 1100. The pixel array 1100 is illustrated with four different configurations over time, including configurations for a first exposure frame 1102, a second exposure frame 1104, a third exposure frame 1106, and a fourth exposure frame 1108. The data sensed by the pixel array 1100 for the multiple exposure frames 1102, 1104, 1106, 1108 can be combined to generate a single RGB image frame. The pixel configurations illustrated in FIG. 11 alternate which subset of pixels are configured as long exposures and which are configured as short exposures on successive green exposure frames. This approach of using long and short exposure pixels increases the perceived resolution of the resultant image. It should be appreciated that the application of dual exposure sampling is not limited to the green exposure frames. In various embodiments, the pixels may have independent dual exposure ratios applied for luminance, red chrominance, blue chrominance, red, green, or blue exposure frames.

[0152] The configuration of the pixels for the first exposure frame 1102 includes green short exposure pixels ("G_S") 1122 and green long exposure pixels ("G_L") 1124 arranged in a checkerboard pattern. The configuration of the pixels for the second exposure frame 1104 includes red pixels ("R") 1120. The configuration of the pixels for the third exposure frame 1106 includes green long exposure pixels 1124 and green short exposure pixels 1122 arranged in a checkerboard pattern in an opposite configuration with respect to the checkerboard pattern of the first exposure frame 1102. The configuration of the pixels for the fourth exposure frame 1108 includes blue pixels ("B") 1126.

[0153] FIG. 12 illustrates a pixel array 1200 of an image sensor similar to those illustrated in FIGS. 8-11 and 13-14. The image sensor is configured for generating a YCbCr image frame based on a plurality of independent exposure frames captured by the pixel array 1200. The pixel array 1200 is illustrated with four different configurations over time, including configurations for a first exposure frame 1202, a second exposure frame 1204, a third exposure frame 1206, and a fourth exposure frame 1208. The data sensed by the pixel array 1200 for the multiple exposure frames 1202, 1204, 1206, 1208 can be combined to generate a single YCbCr image frame. The pixel configuration for the first exposure frame 1202 includes luminance short exposure pixels 1216 and luminance long exposure pixels 1218 arranged in a checkerboard pattern. The pixel configuration of the second exposure frame 1204 includes blue chrominance pixels 1212. The pixel configuration of the third exposure frame 1206 includes luminance long exposure pixels 1218 and luminance short exposure pixels 1216 arrange in a checkerboard pattern opposite to the pattern of the first exposure frame 1202. The pixel configuration of the fourth exposure frame 1208 includes red chrominance pixels 1214.

[0154] FIG. 13 illustrates a pixel array 1300 of an image sensor similar to those illustrated in FIGS. 8-12 and 14. The image sensor is configured for generating an RGB image frame based on a plurality of independent exposure frames captured by the pixel array 1300. The pixel array 1300 is illustrated with four different configurations over time, including configurations for a first exposure frame 1302, a second exposure frame 1304, a third exposure frame 1306, and a fourth exposure frame 1308. The data sensed by the pixel array 1300 for the multiple exposure frames 1302, 1304, 1306, 1308 can be combined to generate a single RGB image frame. The pixel configuration for the first exposure frame 1302 includes green short exposure pixels 1322 and green long exposure pixels 1324 arranged in a checkerboard pattern.

The pixel configuration for the second exposure frame 1304 includes red short exposure pixels ("R_S") 1328 and red long exposure pixels ("R_L") 1330 arranged in a checkerboard pattern. The pixel configuration for the third exposure frame 1306 includes green short exposure pixels 1322 and green long exposure pixels 1324 arranged in a checkerboard pattern opposite to the pattern of the first exposure frame 1302. The pixel configuration for the fourth exposure frame 1308 includes blue short exposure pixels ("B_S") 1332 and blue long exposure pixels ("B_L") 1334 arranged in a checkerboard pattern.

[0155] FIG. 14 illustrates a pixel array 1400 of an image sensor similar to those illustrated in FIGS. 8-13. The image sensor is configured for generating a YCbCr image frame based on a plurality of independent exposure frames captured by the pixel array 1400. The pixel array 1400 is illustrated with four different configurations over time, including configurations for a first exposure frame 1402, a second exposure frame 1404, a third exposure frame 1406, and a fourth exposure frame 1408. The data sensed by the pixel array 1400 for the multiple exposure frames 1402, 1404, 1406, 1408 can be combined to generate a single YCbCr image frame. The pixel configuration for the first exposure frame 1402 includes luminance short exposure pixels 1416 and luminance long exposure pixels 1418 arranged in a checkerboard pattern. The pixel configuration for the second exposure frame 1404 includes blue chrominance short exposure pixels ("Cb_S") 1436 and blue chrominance long exposure pixels ("Cb_L") 1438 arranged in a checkerboard pattern. The pixel configuration for the third exposure frame 1406 includes luminance short exposure pixels 1416 and luminance long exposure pixels 1418 arranged in a checkerboard pattern opposite to the pattern of the first exposure frame 1402. The pixel configuration for the fourth exposure frame 1408 includes red chrominance short exposure pixels ("Cr_S") 1440 and red chrominance long exposure pixels (Cr_L") 1442 arranged in a checkerboard pattern.

[0156] FIG. 15 illustrates a process flow 1500 for applying correction algorithms and frame reconstruction of a YCbCr image frame that further includes specialty imaging data. The specialty imaging data includes one or more of hyperspectral, fluorescence, or laser mapping imaging data. In the case of the Y-Cb-Y-Cr pulsing scheme, the image data is already in the YCbCr color space following color fusion. Therefore, in the process flow 1500 illustrated in FIG. 15, the luminance and chrominance-based operations are performed upfront before converting back to linear RGB color space to perform color corrections.

[0157] The process flow 1500 includes receiving image data from an image sensor at 1502. Sensor correction 1504 is performed on the sensor data. The super resolution (SR) and color motion artifact correction (CMAC) algorithms are implemented at 1506. The SR and CMAC processes 1506 may be performed within the camera image signal processor on raw, captured sensor data. The SR and CMAC processes can be performed at 1506 immediately after all digital sensor correction 1504 processes are completed. The SR and CMAC processes 1506 can be executed before the sensor data is fused into YCbCr space color images. Statistics can be exported at 1508 to determine the appropriate autoexposure for the image.

[0158] A chrominance exposure frame 1510a and a luminance exposure frame 1510b are constructed. In an embodiment, a specialty exposure frame 1510c is also constructed. The luminance exposure frame 1510b is constructed based on the Y frames in arrival order. The chrominance exposure frames 1510a are constructed based on the Cb and Cr frames in arrival order. The number of frames processed by the super resolution algorithm is an optional variable. The first-in-first-out depth of the luminance exposure frame 1510b is normally odd and its size can be determined based on available processing, memory, memory-bandwidth, motion detection precision, or acceptable latency considerations. The color motion artifact correction process can be performed with the minimum first-in-first-out depth of three frames

for luminance and two frames for blue chrominance and/or red chrominance. The super resolution algorithm may generate better resolution by the use of five luminance frames.

[0159] The image data is processed to implement frame reconstruction at 1512 and edge enhancement at 1514. The YCbCr image is converted to a linear RGB image at 1516. Statistics on the RGB image can be exported at 1518 to determine appropriate white balance. The appropriate white balance is applied at 1520 and entered into the color correction matrix at 1522. Scalars 1524 and gamma 1526 are determined and the video is exported at 1528. The process flow 1500 can be implemented in the camera image signal processor in real-time while image data is captured and received from the sensor (see 1502).

[0160] During frame reconstruction 1512, there may be one full color image frame in YCbCr space generated for each luminance exposure frame. The data captured in the luminance exposure frame may be combined with data from chrominance exposure frames captured before and after the luminance exposure frame. Given this pulsing sequence, the position of the blue chrominance exposure frame with respect to the luminance exposure frame may be adjusted to occur before or after the luminance exposure frame for alternate luminance cases. The same is true for the red chrominance exposure frame with respect to the luminance exposure frame. Therefore, the data from each captured blue chrominance or red chrominance exposure frame is used in two resultant full color images. The minimum frame latency may be provided by performing the frame reconstruction 1512 process during the blue chrominance and red chrominance frame capture.

[0161] FIG. 16 is a schematic diagram of a process flow 1600 to be implemented by a controller and/or monochrome image signal processor (ISP) for generating a video stream having RGB images with specialty data overlaid thereon. The specialty data includes one or more of hyperspectral, fluorescence, or laser mapping data. In the process flow 1600, before applying gamma 1626 to place the image data in the standard sRGB color space, additional operations including edge enhancement 1620 and other adjustments are performed in an alternative color space such as the YCbCr or HSL color spaces. In the example process flow 1600, the RGB image data is converted to YCbCr to apply edge enhancement 1620 in the luminance plane and conduct filtering of the chrominance planes, and then the YCbCr image is converted back to linear RGB color space.

[0162] The process flow 1600 results in images with increased dynamic range. The image signal processor (ISP) chain may be assembled for the purpose of generating sRGB image sequences from raw sensor data, yielded in the presence of the G-R-G-B-Specialty light pulsing scheme. In the process flow 1600, the first stage is concerned with making corrections to account for any non-idealities in the sensor technology for which it is most appropriate to work in the raw data domain. At the next stage, multiple frames (for example, a green frame 1612a, a red-blue frame 1612b, and a specialty frame 1612c) are buffered because each final frame derives data from multiple raw frames. The frame reconstruction at 1614 proceeds by sampling data from a current frame and buffered frames (see 1612a, 1612b, and/or 1612c). The reconstruction process results in full color frames in linear RGB color space that include specialty image data.

[0163] In an embodiment, the process flow 1600 is applied to checkerboard readings from a pixel array (see FIGS. 8-14). The checkerboard readings may be sensed in response to an R-G-B-G-Specialty or Y-Cb-Y-Cr-Specialty pulsing scheme. The process flow 1600 includes receiving data from an image sensor at 1602. Sensor correction calculations are performed at 1604. These sensor correction calculations can be used to determine statistics at 1606 such as autoexposure settings and wide dynamic range settings. The process flow 1600 continues and wide dynamic range fusion

is processed at 1608. Wide dynamic range compression is processed at 1610. The wide dynamic range compression from 1610 can be fed to generate a green frame 1612a, a red-blue frame 1612, and/or a specialty frame 1612c. The process flow 1600 continues and frame reconstruction is processed at 1614 and then color correction is processed at 1616. The process flow 1600 continues and an RGB (red-green-blue) image is converted to a YCbCr image at 1618. Edge enhancement is processed at 1620 and then the YCbCr image is converted back to an RGB image at 1622. Scalars are processed at 1624 and gamma is processed at 1626. The video is then exported at 1628.

[0164] In an embodiment, the wide dynamic range fusion at 1608 is executed after dark frame subtraction such that the mean black offset has been adjusted to zero and the data may be signed. In an embodiment, it is desirable to have the fixed pattern noise removed. The aim of the wide dynamic range fusion 1608 process may be to combine the data from two or more separate exposure frames into a single image frame prior to color fusion. This may be accomplished by separating the two components of the checkerboard pattern into two separate buffers and filling in the gaps by interpolation. There may be only one general kernel required because every empty pixel sees the same local environment except for pixels near the edges of the image. A suitable convolution kernel for filling in the checkerboard pattern by simple linear interpolation is:

$$\begin{pmatrix} 0 & \frac{1}{4} & 0 \\ \frac{1}{4} & 0 & \frac{1}{4} \\ 0 & \frac{1}{4} & 0 \end{pmatrix}$$

[0165] Following interpolation there may be two samples for each pixel location. A gain may be applied to the short exposure sample, which may be equal to the exposure-time ratio, $\boldsymbol{T_L/T_S}$. This requires the addition of one extra bit for each factor-two of ratio. The fusion itself involves making a weighted sum of the two samples:

$$x_f = \gamma \cdot \left(\frac{T_L}{T_S}\right) \cdot x_S + (1-\gamma)x_L$$

[0166] Where x_S and x_L may be the (signed) short and long exposure signals respectively. The γ factor may be a function of the long exposure signal, x_L, and may be set according to two thresholds, τ_1 and τ_2. Below $x_L = \tau_1$, $\gamma = 0.0$, above $\gamma = \tau_2$, $\gamma = 1.0$. Between the thresholds, various functional forms may be employed and linear and cubic example behaviors of γ between τ_1 and τ_2, may be drawn. The value of τ_2 may be set to the maximum possible value of x_L, e.g., or something just below it. The purpose of the lower threshold, τ_1, may be to limit the influence of read noise from the short sample which has the gain factor T_L/T_S applied to it. It can be set to a conservatively high constant, to accommodate the maximum ratio E, but it may be more beneficial to have it vary linearly with T_L/T_S;

$$\tau_1 = \left(\frac{T_L}{T_S}\right) \cdot \eta$$

[0167] The provision of two or more exposure frames within the same image frame within a pulsed illumination endoscopy system may also be exploited for the purpose of reducing the number of captured exposure frames per final full-color image from, from three to two. This suppresses possible color motion artifacts that may be associated with an endoscopic imaging system.

[0168] An inherent property of the monochrome wide dynamic range array may be that the pixels that have the long integration time may be integrate a superset of the light seen by the short integration time pixels. For regular wide dynamic operation in the luminance exposure frames, that may be desirable. For the chrominance exposure frames, it

means that the pulsing may be controlled in conjunction with the exposure periods so as to e.g. provide λY+Cb from the start of the long exposure and switch to δY+Cr at the point that the short pixels may be turned on (both pixel types have their charges transferred at the same time). λ and δ may be two tunable factors that may be used to bring all pulse energies to positive values.

[0169] During color correction 1616 in the ISP, the two flavors of pixel may be separated into two buffers. The empty pixels are filled in using linear interpolation. At this point, one buffer would contain a full image of δY+Cr data and the other contains δY+Cr+λY+Cb imaging data. The δY+Cr buffer would be subtracted from the second buffer to give λY+Cb. Then the appropriate proportion of luminance data from the luminance exposure frames would be subtracted out for each.

[0170] FIG. 17 is an example of color fusion hardware 1700. The color fusion hardware 1700 is deployed for generating an image frame according to a pulsed lighting scheme as discussed herein. The color fusion process is more straightforward than de-mosaic, which is necessitated by image sensors with a color filter array, because there is no spatial interpolation. The color fusion process performed by the color fusion hardware 1700 does not require buffering of exposure frames to have all necessary information available for each pixel.

[0171] The memory writer 1702 receives a video data stream. In an embodiment, the video data stream includes Y-Cb-Y-Cr-Y-Cb-Y-Specialty exposure frames. In an alternative embodiment, the video data stream includes R-G-B-G-Specialty exposure frames. The video data stream may include YCbCr or RGB exposure frames in combination with one or more of fluorescence exposure frames, hyperspectral exposure frames, and/or laser mapping or tool tracking exposure frames.

[0172] The memory writer 1702 writes the video data stream to memory 1704. The video data stream may be parsed into, for example, a Cb+δY exposure frame, one or more luminance exposure frames, a Cr+λY exposure frame, a hyperspectral exposure frame, a fluorescence exposure frame, and/or a laser mapping exposure frame. Alternatively, the video data stream may be parsed into, for example, a red exposure frame, one or more green exposure frames, a blue exposure frame, a hyperspectral exposure frame, a fluorescence exposure frame, and/or a laser mapping exposure frame. The different exposure frames are read by the memory reader 1706 and a parallel RGB video data stream is generated at 1708. The pulse generator and frame sync 1710 sends information to the memory writer 1704 and the memory reader 1706 to aid in fusing the multiple exposure frames. Information is output to the light source by the pulse generator and frame sync 1710.

[0173] FIG. 18 illustrates two corresponding histograms of black-corrected signal for a region of an exposure frame. One of the histograms may be used, as mentioned earlier, to control the pulse energy level by comparing a chosen percentile (P_L) of the distribution to a target signal level (S_L, e.g. 50% of the digital dynamic range). The exposure time of these type-1 pixels, T_L, may be held at maximum. The subscript L here denotes the long exposure. The other histogram may be used to monitor the dynamic range of the scene by comparing another chosen percentile of the distribution, P_S, where $P_S > P_L$, and comparing that with a different signal level, S_S, where $S_S > S_L$. The subscript S denotes the short exposure. S_S may be generally tuned close to the top of the digital dynamic range. If $P_S \leq S_S$, the exposure time for these type-2 pixels, T_S, may be also held at maximum. If $P_S > S_S$, then T_S may be lowered until $P_S = S_S$. There may be a predefined limit (E) as to how much the exposure time ratio may be allowed to increase to ensure that image quality degradation due to dynamic range enhancement outweighs the benefit of enhancing the dynamic range. The values of P_L, P_S, S_L, S_S and E may be tuned differently according to different applications and stored as factory presets. The

exposure times T_L and T_S may be recorded for each exposure frame type, for use by the wide dynamic range fusion process and by the color fusion ISP stage. In the case that the red, green, blue, and specialty pulse energies are modulated for the purpose of white balance, the exposure times on the red and blue frames may be governed by the green frames which may be exclusively used to gather the wide dynamic range statistics.

[0174] In an implementation in which the imaging system is pulsing for luminance and chrominance illumination to generate a YCbCr image frame, the relative pulse energies may be held constant for a particular type of exposure frame. The wide dynamic range control may be applied for the luminance frames as a baseline with the option of also applying wide dynamic range independently on the chrominance frames. The histograms may be constructed on the raw black-corrected frame data as for the R-G-B-G scheme. Again, the exposure times for each frame type may be recorded for wide dynamic range fusion and for color fusion.

[0175] FIG. 19A shows the general situation of pipelining of data for the Y-Cb-Y-Cr pattern which yields one full color image per two raw captured images. This is accomplished by using each chrominance sample twice. In additional embodiments, the data for the Y-Cb-Y-Cr pattern may further include data for hyperspectral, fluorescence, and/or laser mapping imaging.

[0176] FIG. 19B is an example of a 120Hz frame capture rate providing a 60Hz final video stream. The linear Y, Cb, and Cr components for each pixel may be computed as follows:

$$\boldsymbol{Y_i = 2^{m-4} + (x_{i,n-1} - K)}$$

$$\left.\begin{matrix}\boldsymbol{Cb_i = 2^{m-1} + (x_{i,n} - K) - \lambda \cdot (x_{i,n-1} - K)} \\ \boldsymbol{Cr_i = 2^{m-1} + (x_{i,n-2} - K) - \delta \cdot (x_{i,n-1} - K)}\end{matrix}\right\} \text{when } \boldsymbol{n} = \text{'Cb' frame}$$

$$\left.\begin{matrix}\boldsymbol{Cb_i = 2^{m-1} + (x_{i,n-2} - K) - \lambda \cdot (x_{i,n-1} - K)} \\ \boldsymbol{Cr_i = 2^{m-1} + (x_{i,n} - K) - \delta \cdot (x_{i,n-1} - K)}\end{matrix}\right\} \text{when } \boldsymbol{n} = \text{'Cr' frame}$$

[0177] Where $x_{i,n}$ is the input data for pixel i in frame n, m is the pipeline bit-width of the ISP and K is the ISP black offset level at the input to the color fusion block, (if applicable). Since chrominance is signed it is conventionally centered at 50% of the digital dynamic range (2^{m-1}).

[0178] If two exposures are used to provide both chrominance components in the same frame as described earlier, the two flavors of pixel are separated into two buffers. The empty pixels are then filled in using, e.g., linear interpolation. At this point, one buffer contains a full image of δY+Cr data and the other; δY+Cr+λY+Cb. The δY+Cr buffer is subtracted from the second buffer to give λY+Cb. Then the appropriate proportion of luminance data from the Y frames is subtracted out for each.

[0179] FIG. 20 is a schematic diagram of a pattern reconstruction process. The example pattern illustrated in FIG. 20 includes Red, Green, Blue, and Specialty pulses of light that each last a duration of T1. In various embodiments, the pulses of light may be of the same duration or of differing durations. The Red, Green, Blue, and Specialty exposure frames are combined to generate an RGB image with specialty data overlaid thereon. A single image frame comprising a red exposure frame, a green exposure frame, a blue exposure frame, and a specialty exposure frame requires a time period of 4*T1 to be generated. The time durations shown in FIG. 20 are illustrative only and may vary for different implementations. In other embodiments, different pulsing schemes may be employed. For example, embodiments may be based on the timing of each color component or frame (T1) and the reconstructed frame having a period twice that of the incoming color frame (2 x T1). Different frames within the sequence may have different frame periods and the average capture rate could be any multiple of the final frame rate.

[0180] In an embodiment, the dynamic range of the system is increased by varying the pixel sensitivities of pixels within the pixel array of the image sensor. Some pixels may sense reflected electromagnetic radiation at a first sensitivity level, other pixels may sense reflected electromagnetic radiation at a second sensitivity level, and so forth. The different pixel sensitivities may be combined to increase the dynamic range provided by the pixel configuration of the image sensor. In an embodiment, adjacent pixels are set at different sensitivities such that each cycle includes data produced by pixels that are more and less sensitive with respect to each other. The dynamic range is increased when a plurality of sensitivities are recorded in a single cycle of the pixel array. In an embodiment, wide dynamic range can be achieved by having multiple global TX, each TX firing only on a different set of pixels. For example, in global mode, a global TX1 signal is firing a set 1 of pixels, a global TX2 signal is firing a set 2 of pixel, a global TXn signal is firing a set n of pixels, and so forth.

[0181] FIGS. 21A-21C each illustrate a light source 2100 having a plurality of emitters. The emitters include a first emitter 2102, a second emitter 2104, and a third emitter 2106. Additional emitters may be included, as discussed further below. The emitters 2102, 2104, and 2106 may include one or more laser emitters that emit light having different wavelengths. For example, the first emitter 2102 may emit a wavelength that is consistent with a blue laser, the second emitter 2104 may emit a wavelength that is consistent with a green laser, and the third emitter 2106 may emit a wavelength that is consistent with a red laser. For example, the first emitter 2102 may include one or more blue lasers, the second emitter 2104 may include one or more green lasers, and the third emitter 2106 may include one or more red lasers. The emitters 2102, 2104, 2106 emit laser beams toward a collection region 2108, which may be the location of a waveguide, lens, or other optical component for collecting and/or providing light to a waveguide, such as the jumper waveguide 206 or lumen waveguide 210 of FIG. 2.

[0182] In an implementation, the emitters 2102, 2104, and 2106 emit hyperspectral wavelengths of electromagnetic radiation. Certain hyperspectral wavelengths may pierce through tissue and enable a medical practitioner to "see through" tissues in the foreground to identify chemical processes, structures, compounds, biological processes, and so forth that are located behind the tissues in the foreground. The hyperspectral wavelengths may be specifically selected to identify a specific disease, tissue condition, biological process, chemical process, type of tissue, and so forth that is known to have a certain spectral response.

[0183] In an implementation where a patient has been administered a reagent or dye to aid in the identification of certain tissues, structures, chemical reactions, biological processes, and so forth, the emitters 2102, 2104, and 2106 may emit wavelength(s) for fluorescing the reagents or dyes. Such wavelength(s) may be determined based on the reagents or dyes administered to the patient. In such an embodiment, the emitters may need to be highly precise for emitting desired wavelength(s) to fluoresce or activate certain reagents or dyes.

[0184] In an implementation, the emitters 2102, 2104, and 2106 emit a laser mapping pattern for mapping a topology of a scene and/or for calculating dimensions and distances between objects in the scene. In an embodiment, the endoscopic imaging system is used in conjunction with multiple tools such as scalpels, retractors, forceps, and so forth. In such an embodiment, each of the emitters 2102, 2104, and 2106 may emit a laser mapping pattern such that a laser mapping pattern is projected on to each tool individually. In such an embodiment, the laser mapping data for each of the tools can be analyzed to identify distances between the tools and other objects in the scene.

[0185] In the embodiment of FIG. 21B, the emitters 2102, 2104, 2106 each deliver laser light to the collection region 2108 at different angles. The variation in angle can lead to variations where electromagnetic energy is located in

an output waveguide. For example, if the light passes immediately into a fiber bundle (glass or plastic) at the collection region 2108, the varying angles may cause different amounts of light to enter different fibers. For example, the angle may result in intensity variations across the collection region 2108. Furthermore, light from the different emitters may not be homogenously mixed so some fibers may receive different amounts of light of different colors. Variation in the color or intensity of light in different fibers can lead to non-optimal illumination of a scene. For example, variations in delivered light or light intensities may result at the scene and captured images.

[0186] In one embodiment, an intervening optical element may be placed between a fiber bundle and the emitters 2102, 2104, 2106 to mix the different colors (wavelengths) of light before entry into the fibers or other waveguide. Example intervening optical elements include a diffuser, mixing rod, one or more lenses, or other optical components that mix the light so that a given fiber receive a same amount of each color (wavelength). For example, each fiber in the fiber bundle may have a same color. This mixing may lead to the same color in each fiber but may, in some embodiments, still result in different total brightness delivered to different fibers. In one embodiment, the intervening optical element may also spread out or even out the light over the collection region so that each fiber carries the same total amount of light (e.g., the light may be spread out in a top hat profile). A diffuser or mixing rod may lead to loss of light.

[0187] Although the collection region 2108 is represented as a physical component in FIG. 21A, the collection region 2108 may simply be a region where light from the emitters 2102, 2104, and 2106 is delivered. In some cases, the collection region 2108 may include an optical component such as a diffuser, mixing rod, lens, or any other intervening optical component between the emitters 2102, 2104, 2106 and an output waveguide.

[0188] FIG. 21C illustrates an embodiment of a light source 2100 with emitters 2102, 2104, 2106 that provide light to the collection region 2108 at the same or substantially same angle. The light is provided at an angle substantially perpendicular to the collection region 2108. The light source 2100 includes a plurality of dichroic mirrors including a first dichroic mirror 2110, a second dichroic mirror 2112, and a third dichroic mirror 2114. The dichroic mirrors 2110, 2112, 2114 include mirrors that reflect a first wavelength of light but transmit (or are transparent to) a second wavelength of light. For example, the third dichroic mirror 2114 may reflect blue laser light provided by the third emitter, while being transparent to the red and green light provided by the first emitter 2102 and the second emitter 2104, respectively. The second dichroic mirror 2112 may be transparent to red light from the first emitter 2102, but reflective to green light from the second emitter 2104. If other colors or wavelengths are included dichroic mirrors may be selected to reflect light corresponding to at least one emitter and be transparent to other emitters. For example, the third dichroic mirror 2114 reflect the light form the third emitter 2106 but is to emitters “behind” it, such as the first emitter 2102 and the second emitter 2104. In embodiments where tens or hundreds of emitters are present, each dichroic mirror may be reflective to a corresponding emitter and emitters in front of it while being transparent to emitters behind it. This may allow for tens or hundreds of emitters to emit electromagnetic energy to the collection region 2108 at a substantially same angle.

[0189] Because the dichroic mirrors allow other wavelengths to transmit or pass through, each of the wavelengths may arrive at the collection region 2108 from a same angle and/or with the same center or focal point. Providing light from the same angle and/or same focal/center point can significantly improve reception and color mixing at the collection region 2108. For example, a specific fiber may receive the different colors in the same proportions they were transmitted/reflected by the emitters 2102, 2104, 2106 and mirrors 2110, 2112, 2114. Light mixing may be significantly

improved at the collection region compared to the embodiment of FIG. 21B. In one embodiment, any optical components discussed herein may be used at the collection region 2108 to collect light prior to providing it to a fiber or fiber bundle.

[0190] FIG. 21C illustrates an embodiment of a light source 2100 with emitters 2102, 2104, 2106 that also provide light to the collection region 2108 at the same or substantially same angle. However, the light incident on the collection region 2108 is offset from being perpendicular. Angle 2116 indicates the angle offset from perpendicular. In one embodiment, the laser emitters 2102, 2104, 2106 may have cross sectional intensity profiles that are Gaussian. As discussed previously, improved distribution of light energy between fibers may be accomplished by creating a more flat or top-hat shaped intensity profile. In one embodiment, as the angle 2116 is increased, the intensity across the collection region 2108 approaches a top hat profile. For example, a top-hat profile may be approximated even with a non-flat output beam by increasing the angle 2116 until the profile is sufficiently flat. The top hat profile may also be accomplished using one or more lenses, diffusers, mixing rods, or any other intervening optical component between the emitters 2102, 2104, 2106 and an output waveguide, fiber, or fiber optic bundle.

[0191] FIG. 22 is a schematic diagram illustrating a single optical fiber 2202 outputting via a diffuser 2204 at an output. In one embodiment, the optical fiber 2202 has a diameter of 500 microns, a numerical aperture of 0.65, and emits a light cone 2206 of about 70 or 80 degrees without a diffuser 2204. With the diffuser 2204, the light cone 2206 may have an angle of about 110 or 120 degrees. The light cone 2206 may be a majority of where all light goes and is evenly distributed. The diffuser 2204 may allow for more even distribution of electromagnetic energy of a scene observed by an image sensor.

[0192] In one embodiment, the lumen waveguide 210 includes a single plastic or glass optical fiber of about 500 microns. The plastic fiber may be low cost, but the width may allow the fiber to carry a sufficient amount of light to a scene, with coupling, diffusion, or other losses. For example, smaller fibers may not be able to carry as much light or power as a larger fiber. The lumen waveguide 210 may include a single or a plurality of optical fibers. The lumen waveguide 210 may receive light directly from the light source or via a jumper waveguide. A diffuser may be used to broaden the light output 206 for a desired field of view of the image sensor 214 or other optical components.

[0193] Although three emitters are shown in FIGS. 21A-21C, emitters numbering from one into the hundreds or more may be used in some embodiments. The emitters may have different wavelengths or spectrums of light that they emit, and which may be used to contiguously cover a desired portion of the electromagnetic spectrum (e.g., the visible spectrum as well as infrared and ultraviolet spectrums). The emitters may be configured to emit visible light such as red light, green light, and blue light, and may further be configured to emit hyperspectral emissions of electromagnetic radiation, fluorescence excitation wavelengths for fluorescing a reagent, and/or laser mapping patterns for calculating parameters and distances between objects in a scene.

[0194] FIG. 23 illustrates a portion of the electromagnetic spectrum 2300 divided into twenty different sub-spectrums. The number of sub-spectrums is illustrative only. In at least one embodiment, the spectrum 2300 may be divided into hundreds of sub-spectrums, each with a small waveband. The spectrum may extend from the infrared spectrum 2302, through the visible spectrum 2304, and into the ultraviolet spectrum 2306. The sub-spectrums each have a waveband 2308 that covers a portion of the spectrum 2300. Each waveband may be defined by an upper wavelength and a lower wavelength.

[0195] Hyperspectral imaging incudes imaging information from across the electromagnetic spectrum 2300. A hyperspectral pulse of electromagnetic radiation may include a plurality of sub-pulses spanning one or more portions of

the electromagnetic spectrum 2300 or the entirety of the electromagnetic spectrum 2300. A hyperspectral pulse of electromagnetic radiation may include a single partition of wavelengths of electromagnetic radiation. A resulting hyperspectral exposure frame includes information sensed by the pixel array subsequent to a hyperspectral pulse of electromagnetic radiation. Therefore, a hyperspectral exposure frame may include data for any suitable partition of the electromagnetic spectrum 2300 and may include multiple exposure frames for multiple partitions of the electromagnetic spectrum 2300. In an embodiment, a hyperspectral exposure frame includes multiple hyperspectral exposure frames such that the combined hyperspectral exposure frame comprises data for the entirety of the electromagnetic spectrum 2300.

[0196] In one embodiment, at least one emitter (such as a laser emitter) is included in a light source (such as the light sources 202, 2100) for each sub-spectrum to provide complete and contiguous coverage of the whole spectrum 2300. For example, a light source for providing coverage of the illustrated sub-spectrums may include at least 20 different emitters, at least one for each sub-spectrum. In one embodiment, each emitter covers a spectrum covering 40 nanometers. For example, one emitter may emit light within a waveband from 500 nm to 540 nm while another emitter may emit light within a waveband from 540 nm to 580 nm. In another embodiment, emitters may cover other sizes of wavebands, depending on the types of emitters available or the imaging needs. For example, a plurality of emitters may include a first emitter that covers a waveband from 500 to 540 nm, a second emitter that covers a waveband from 540 nm to 640 nm, and a third emitter that covers a waveband from 640 nm to 650 nm. Each emitter may cover a different slice of the electromagnetic spectrum ranging from far infrared, mid infrared, near infrared, visible light, near ultraviolet and/or extreme ultraviolet. In some cases, a plurality of emitters of the same type or wavelength may be included to provide sufficient output power for imaging. The number of emitters needed for a specific waveband may depend on the sensitivity of a monochrome sensor to the waveband and/or the power output capability of emitters in that waveband.

[0197] The waveband widths and coverage provided by the emitters may be selected to provide any desired combination of spectrums. For example, contiguous coverage of a spectrum using very small waveband widths (e.g., 10 nm or less) may allow for highly selective hyperspectral and/or fluorescence imaging. The waveband widths may allow for selectively emitting the excitation wavelength(s) for one or more particular fluorescent reagents. Additionally, the waveband widths may allow for selectively emitting certain partitions of hyperspectral electromagnetic radiation for identifying specific structures, chemical processes, tissues, biological processes, and so forth. Because the wavelengths come from emitters which can be selectively activated, extreme flexibility for fluorescing one or more specific fluorescent reagents during an examination can be achieved. Additionally, extreme flexibility for identifying one or more objects or processes by way of hyperspectral imaging can be achieved. Thus, much more fluorescence and/or hyperspectral information may be achieved in less time and within a single examination which would have required multiple examinations, delays because of the administration of dyes or stains, or the like.

[0198] FIG. 24 is a schematic diagram illustrating a timing diagram 2400 for emission and readout for generating an image. The solid line represents readout (peaks 2402) and blanking periods (valleys) for capturing a series of exposure frames 2404-2414. The series of exposure frames 2404-2414 may include a repeating series of exposure frames which may be used for generating laser mapping, hyperspectral, and/or fluorescence data that may be overlaid on an RGB video stream. In an embodiment, a single image frame comprises information from multiple exposure frames, wherein one exposure frame includes red image data, another exposure frame includes green image data, and another exposure frame includes blue image data. Additionally, the single image frame may include one or more of hyperspectral image

data, fluorescence image data, and laser mapping data. The multiple exposure frames are combined to produce the single image frame. The single image frame is an RGB image with hyperspectral imaging data. The series of exposure frames include a first exposure frame 2404, a second exposure frame 2406, a third exposure frame 2408, a fourth exposure frame 2410, a fifth exposure frame 2412, and an Nth exposure frame 2426.

[0199] Additionally, the hyperspectral image data, the fluorescence image data, and the laser mapping data can be used in combination to identify critical tissues or structures and further to measure the dimensions of those critical tissues or structures. For example, the hyperspectral image data may be provided to a corresponding system to identify certain critical structures in a body such as a nerve, ureter, blood vessel, cancerous tissue, and so forth. The location and identification of the critical structures may be received from the corresponding system and may further be used to generate topology of the critical structures using the laser mapping data. For example, a corresponding system determines the location of a cancerous tumor based on hyperspectral imaging data. Because the location of the cancerous tumor is known based on the hyperspectral imaging data, the topology and distances of the cancerous tumor may then be calculated based on laser mapping data. This example may also apply when a cancerous tumor or other structure is identified based on fluorescence imaging data.

[0200] In one embodiment, each exposure frame is generated based on at least one pulse of electromagnetic energy. The pulse of electromagnetic energy is reflected and detected by an image sensor and then read out in a subsequent readout (2402). Thus, each blanking period and readout results in an exposure frame for a specific spectrum of electromagnetic energy. For example, the first exposure frame 2404 may be generated based on a spectrum of a first one or more pulses 2416, a second exposure frame 2406 may be generated based on a spectrum of a second one or more pulses 2418, a third exposure frame 2408 may be generated based on a spectrum of a third one or more pulses 2420, a fourth exposure frame 2410 may be generated based on a spectrum of a fourth one or more pulses 2422, a fifth exposure frame 2412 may be generated based on a spectrum of a fifth one or more pulses 2424, and an Nth exposure frame 2426 may be generated based on a spectrum of an Nth one or more pulses 2426.

[0201] The pulses 2416-2426 may include energy from a single emitter or from a combination of two or more emitters. For example, the spectrum included in a single readout period or within the plurality of exposure frames 2404-2414 may be selected for a desired examination or detection of a specific tissue or condition. According to one embodiment, one or more pulses may include visible spectrum light for generating an RGB or black and white image while one or more additional pulses are emitted to sense a spectral response to a hyperspectral wavelength of electromagnetic radiation. For example, pulse 2416 may include red light, pulse 2418 may include blue light, and pulse 2420 may include green light while the remaining pulses 2422-2426 may include wavelengths and spectrums for detecting a specific tissue type, fluorescing a reagent, and/or mapping the topology of the scene. As a further example, pulses for a single readout period include a spectrum generated from multiple different emitters (e.g., different slices of the electromagnetic spectrum) that can be used to detect a specific tissue type. For example, if the combination of wavelengths results in a pixel having a value exceeding or falling below a threshold, that pixel may be classified as corresponding to a specific type of tissue. Each frame may be used to further narrow the type of tissue that is present at that pixel (e.g., and each pixel in the image) to provide a very specific classification of the tissue and/or a state of the tissue (diseased/healthy) based on a spectral response of the tissue and/or whether a fluorescent reagent is present at the tissue.

[0202] The plurality of frames 2404-2414 is shown having varying lengths in readout periods and pulses having different lengths or intensities. The blanking period, pulse length or intensity, or the like may be selected based on the sensitivity of a monochromatic sensor to the specific wavelength, the power output capability of the emitter(s), and/or the carrying capacity of the waveguide.

[0203] In one embodiment, dual image sensors may be used to obtain three-dimensional images or video feeds. A three-dimensional examination may allow for improved understanding of a three-dimensional structure of the examined region as well as a mapping of the different tissue or material types within the region.

[0204] In an example implementation, a fluorescent reagent is provided to a patient, and the fluorescent reagent is configured to adhere to cancerous cells. The fluorescent reagent is known to fluoresce when radiated with a specific partition of electromagnetic radiation. The relaxation wavelength of the fluorescent reagent is also known. In the example implementation, the patient is imaged with an endoscopic imaging system as discussed herein. The endoscopic imaging system pulses partitions of red, green, and blue wavelengths of light to generate an RGB video stream of the interior of the patient's body. Additionally, the endoscopic imaging system pulses the excitation wavelength of electromagnetic radiation for the fluorescent reagent that was administered to the patient. In the example, the patient has cancerous cells and the fluorescent reagent has adhered to the cancerous cells. When the endoscopic imaging system pulses the excitation wavelength for the fluorescent reagent, the fluorescent reagent will fluoresce and emit a relaxation wavelength. If the cancerous cells are present in the scene being imaged by the endoscopic imaging system, then the fluorescent reagent will also be present in the scene and will emit its relaxation wavelength after fluorescing due to the emission of the excitation wavelength. The endoscopic imaging system senses the relaxation wavelength of the fluorescent reagent and thereby senses the presence of the fluorescent reagent in the scene. Because the fluorescent reagent is known to adhere to cancerous cells, the presence of the fluorescent reagent further indicates the presence of cancerous cells within the scene. The endoscopic imaging system thereby identifies the location of cancerous cells within the scene. The endoscopic imaging system may further emit a laser mapping pulsing scheme for generating a topology of the scene and calculating dimensions for objects within the scene. The location of the cancerous cells (as identified by the fluorescence imaging data) may be combined with the topology and dimensions information calculated based on the laser mapping data. Therefore, the precise location, size, dimensions, and topology of the cancerous cells may be identified. This information may be provided to a medical practitioner to aid in excising the cancerous cells. Additionally, this information may be provided to a robotic surgical system to enable the surgical system to excise the cancerous cells.

[0205] In a further example implementation, a patient is imaged with an endoscopic imaging system to identify quantitative diagnostic information about the patient's tissue pathology. In the example, the patient is suspected or known to suffer from a disease that can be tracked with hyperspectral imaging to observe the progression of the disease in the patient's tissue. The endoscopic imaging system pulses partitions of red, green, and blue wavelengths of light to generate an RGB video stream of the interior of the patient's body. Additionally, the endoscopic imaging system pulses one or more hyperspectral wavelengths of light that permit the system to "see through" some tissues and generate imaging of the tissue that is affected by the disease. The endoscopic imaging system senses the reflected hyperspectral electromagnetic radiation to generate hyperspectral imaging data of the diseased tissue, and thereby identifies the location of the diseased tissue within the patient's body. The endoscopic imaging system may further emit a laser mapping pulsing scheme for generating a topology of the scene and calculating dimensions of objects within the scene.

The location of the diseased tissue (as identified by the hyperspectral imaging data) may be combined with the topology and dimensions information that is calculated with the laser mapping data. Therefore, the precise location, size, dimensions, and topology of the diseased tissue can be identified. This information may be provided to a medical practitioner to aid in excising, imaging, or studying the diseased tissue. Additionally, this information may be provided to a robotic surgical system to enable the surgical system to excise the diseased tissue.

[0206] FIG. 25 is a schematic diagram of an imaging system 2500 having a single cut filter. The system 2500 includes an endoscope 2506 or other suitable imaging device having a light source 2508 for use in a light deficient environment. The endoscope 2506 includes an image sensor 2504 and a filter 2502 for filtering out unwanted wavelengths of light or other electromagnetic radiation before reaching the image sensor 2504. The light source 2508 transmits light that may illuminate the surface 2512 in a light deficient environment such as a body cavity. The light 2510 is reflected off the surface 2512 and passes through the filter 2502 before hitting the image sensor 2504.

[0207] The filter 2502 may be used in an implementation where a fluorescent reagent or dye has been administered. In such an embodiment, the light source 2508 emits the excitation wavelength for fluorescing the fluorescent reagent or dye. Commonly, the relaxation wavelength emitted by the fluorescent reagent or dye will be of a different wavelength than the excitation wavelength. The filter 2502 may be selected to filter out the excitation wavelength and permit only the relaxation wavelength to pass through the filter and be sensed by the image sensor 2504.

[0208] In one embodiment, the filter 2502 is configured to filter out an excitation wavelength of electromagnetic radiation that causes a reagent or dye to fluoresce such that only the expected relaxation wavelength of the fluoresced reagent or dye is permitted to pass through the filter 2502 and reach the image sensor 2504. In an embodiment, the filter 2502 filters out at least a fluorescent reagent excitation wavelength between 770 nm and 790 nm. In an embodiment, the filter 2502 filters out at least a fluorescent reagent excitation wavelength between 795 nm and 815 nm. In an embodiment, the filter 2502 filters out at least a fluorescent reagent excitation wavelength between 770 nm and 790 nm and between 795 nm and 815 nm. In these embodiments, the filter 2502 filters out the excitation wavelength of the reagent and permits only the relaxation wavelength of the fluoresced reagent to be read by the image sensor 2504. The image sensor 2504 may be a wavelength-agnostic image sensor and the filter 2502 may be configured to permit the image sensor 2504 to only receive the relaxation wavelength of the fluoresced reagent and not receive the emitted excitation wavelength for the reagent. The data determined by the image sensor 2504 may then indicate a presence of a critical body structure, tissue, biological process, or chemical process as determined by a location of the reagent or dye.

[0209] The filter 2502 may further be used in an implementation where a fluorescent reagent or dye has not been administered. The filter 2502 may be selected to permit wavelengths corresponding to a desired spectral response to pass through and be read by the image sensor 2504. The image sensor 2504 may be a monochromatic image sensor such that pixels of the captured image that exceed a threshold or fall below a threshold may be characterized as corresponding to a certain spectral response or fluorescence emission. The spectral response or fluorescence emission, as determined by the pixels captured by the image sensor 2504, may indicate the presence of a certain body tissue or structure, a certain condition, a certain chemical process, and so forth.

[0210] FIG. 26 is a schematic diagram of an imaging system 2600 having multiple cut filters. The system 2600 includes an endoscope 2606 or other suitable imaging device having a light source 2608 for use in a light deficient environment. The endoscope 2606 includes an image sensor 2604 and two filters 2602a, 2602b. It should be appreciated that in alternative embodiments, the system 2600 may include any number of filters, and the number of filters and the

type of filters may be selected for a certain purpose *e.g.,* for gathering imaging information of a particular body tissue, body condition, chemical process, and so forth. The filters 2602a, 2602b are configured for preventing unwanted wavelengths of light or other electromagnetic radiation from being sensed by the image sensor 2604. The filters 2602a, 2602b may be configured to filter out unwanted wavelengths from white light or other electromagnetic radiation that may be emitted by the light source 2608.

[0211] Further to the disclosure with respect to FIG. 25, the filters 2602a, 2602b may be used in an implementation where a fluorescent reagent or dye has been administered. The filters 2602a, 2602b may be configured for blocking an emitted excitation wavelength for the reagent or dye and permitting the image sensor 2604 to only read the relaxation wavelength of the reagent or dye. Further, the filters 2602a, 2602b may be used in an implementation where a fluorescent reagent or dye has not been administered. In such an implementation, the filters 2602a, 2602b may be selected to permit wavelengths corresponding to a desired spectral response to pass through and be read by the image sensor 2604.

[0212] The multiple filters 2602a, 2602b may each be configured for filtering out a different range of wavelengths of the electromagnetic spectrum. For example, one filter may be configured for filtering out wavelengths longer than a desired wavelength range and the additional filter may be configured for filtering out wavelengths shorter than the desired wavelength range. The combination of the two or more filters may result in only a certain wavelength or band of wavelengths being read by the image sensor 2604.

[0213] In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 513 nm and 545 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 565 nm and 585 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 900 nm and 1000 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 425 nm and 475 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 520 nm and 545 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 625 nm and 645 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 760 nm and 795 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 795 nm and 815 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 370 nm and 420 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are customized such that electromagnetic radiation between 600 nm and 670 nm contacts the image sensor 2604. In an embodiment, the filters 2602a, 2602b are configured for permitting only a certain fluorescence relaxation emission to pass through the filters 2602a, 2602b and contact the image sensor 2604. In an embodiment, a first filter blocks electromagnetic radiation having a wavelength from about 770 nm to about 790 nm, and a second filter blocks electromagnetic radiation having a wavelength from about 795 nm to about 815 nm.

[0214] In an embodiment, the system 2600 includes multiple image sensors 2604 and may particularly include two image sensors for use in generating a three-dimensional image. The image sensor(s) 2604 may be color/wavelength agnostic and configured for reading any wavelength of electromagnetic radiation that is reflected off the surface 2612. In an embodiment, the image sensors 2604 are each color dependent or wavelength dependent and configured for reading electromagnetic radiation of a particular wavelength that is reflected off the surface 2612 and back to the image sensors

2604. Alternatively, the image sensor 2604 may include a single image sensor with a plurality of different pixel sensors configured for reading different wavelengths or colors of light, such as a Bayer filter color filter array. Alternatively, the image sensor 2604 may include one or more color agnostic image sensors that may be configured for reading different wavelengths of electromagnetic radiation according to a pulsing schedule such as those illustrated in FIGS. 5-7E, for example.

[0215] FIG. 27 is a schematic diagram illustrating a system 2700 for mapping a surface and/or tracking an object in a light deficient environment through laser mapping imaging. In an embodiment, an endoscope 2706 in a light deficient environment pulses a grid array 2706 (may be referred to as a laser map pattern) on a surface 2704. The grid array 2706 includes vertical hashing 2708 and horizontal hashing 2710 in one embodiment as illustrated in FIG. 27. It should be appreciated the grid array 2706 may include any suitable array for mapping a surface 2704, including, for example, a raster grid of discrete points, an occupancy grid map, a dot array, and so forth. Additionally, the endoscope 2706 may pulse multiple grid arrays 2706 and may, for example, pulse one or more individual grid arrays on each of a plurality of objects or structures within the light deficient environment.

[0216] In an embodiment, the system 2700 pulses a grid array 2706 that may be used for mapping a three-dimensional topology of a surface and/or tracking a location of an object such as a tool or another device in a light deficient environment. In an embodiment, the system 2700 provides data to a third-party system or computer algorithm for determining surface dimensions and configurations by way of light detection and ranging (LIDAR) mapping. The system 2700 may pulse any suitable wavelength of light or electromagnetic radiation in the grid array 2706, including, for example, ultraviolet light, visible, light, and/or infrared or near infrared light. The surface 2704 and/or objects within the environment may be mapped and tracked at very high resolution and with very high accuracy and precision.

[0217] In an embodiment, the system 2700 includes an imaging device having a tube, one or more image sensors, and a lens assembly having an optical element corresponding to the one or more image sensors. The system 2700 may include a light engine having an emitter generating one or more pulses of electromagnetic radiation and a lumen transmitting the one or more pulses of electromagnetic radiation to a distal tip of an endoscope within a light deficient environment such as a body cavity. In an embodiment, at least a portion of the one or more pulses of electromagnetic radiation includes a laser map pattern that is emitted onto a surface within the light deficient environment, such as a surface of body tissue and/or a surface of tools or other devices within the body cavity. The endoscope 2706 may include a two-dimensional, three-dimensional, or n-dimensional camera for mapping and/or tracking the surface, dimensions, and configurations within the light deficient environment.

[0218] In an embodiment, the system 2700 includes a processor for determining a distance of an endoscope or tool from an object such as the surface 2704. The processor may further determine an angle between the endoscope or tool and the object. The processor may further determine surface area information about the object, including for example, the size of surgical tools, the size of structures, the size of anatomical structures, location information, and other positional data and metrics. The system 2700 may include one or more image sensors that provide image data that is output to a control system for determining a distance of an endoscope or tool to an object such as the surface 2704. The image sensors may output information to a control system for determining an angle between the endoscope or tool to the object. Additionally, the image sensors may output information to a control system for determining surface area information about the object, the size of surgical tools, size of structures, size of anatomical structures, location information, and other positional data and metrics.

[0219] In an embodiment, the grid array 2706 is pulsed by an emitter of the endoscope 2706 at a sufficient speed such that the grid array 2706 is not visible to a user. In various implementations, it may be distracting to a user to see the grid array 2706 during an endoscopic imaging procedure and/or endoscopic surgical procedure. The grid array 2706 may be pulsed for sufficiently brief periods such that the grid array 2706 cannot be detected by a human eye. In an alternative embodiment, the endoscope 2706 pulses the grid array 2706 at a sufficient recurring frequency such that the grid array 2706 may be viewed by a user. In such an embodiment, the grid array 2706 may be overlaid on an image of the surface 2704 on a display. The grid array 2706 may be overlaid on a black-and-white or RGB image of the surface 2704 such that the grid array 2706 may be visible by a user during use of the system 2700. A user of the system 2700 may indicate whether the grid array 2706 should be overlaid on an image of the surface 2704 and/or whether the grid array 2706 should be visible to the user. The system 2700 may include a display that provides real-time measurements of a distance from the endoscope 2706 to the surface 2704 or another object within the light deficient environment. The display may further provide real-time surface area information about the surface 2704 and/or any objects, structures, or tools within the light deficient environment. The accuracy of the measurements may be accurate to less than one millimeter.

[0220] In an embodiment, the system 2700 pulses a plurality of grid arrays 2706. In an embodiment, each of the plurality of grid arrays 2706 corresponds to a tool or other device present within the light deficient environment. The precise locations and parameters of each of the tools and other devices may be tracked by pulsing and sensing the plurality of grid arrays 2706. The information generated by sensing the reflected grid arrays 2706 can be assessed to identify relative locations of the tools and other devices within the light deficient environment.

[0221] The endoscope 2706 may pulse electromagnetic radiation according to a pulsing schedule such as those illustrated herein that may further include pulsing of the grid array 2706 along with pulsing Red, Green, and Blue light for generating an RGB image and further generating a grid array 2706 that may be overlaid on the RGB image and/or used for mapping and tracking the surface 2704 and objects within the light deficient environment. The grid array 2706 may additionally be pulsed in conjunction with hyperspectral or fluorescent excitation wavelengths of electromagnetic radiation. The data from each of the RGB imaging, the laser mapping imaging, the hyperspectral imaging, and the fluorescence imaging may be combined to identify the locations, dimensions, and surface topology of critical structures in a body.

[0222] In an embodiment, the endoscope 2706 includes one or more color agnostic image sensors. In an embodiment, the endoscope 2706 includes two color agnostic image sensors for generating a three-dimensional image or map of the light deficient environment. The image sensors may generate an RGB image of the light deficient environment according to a pulsing schedule as disclosed herein. Additionally, the image sensors may determine data for mapping the light deficient environment and tracking one or more objects within the light deficient environment based on data determined when the grid array 2706 is pulsed. Additionally, the image sensors may determine spectral or hyperspectral data along with fluorescence imaging data according to a pulsing schedule that may be modified by a user to suit the particular needs of an imaging procedure. In an embodiment, a pulsing schedule includes Red, Green, and Blue pulses along with pulsing of a grid array 2706 and/or pulsing for generating hyperspectral image data and/or fluorescence image data. In various implementations, the pulsing schedule may include any suitable combination of pulses of electromagnetic radiation according to the needs of a user. The recurring frequency of the different wavelengths of electromagnetic radiation may be determined based on, for example, the energy of a certain pulse, the

needs of the user, whether certain data (for example, hyperspectral data and/or fluorescence imaging data) needs to be continuously updated or may be updated less frequently, and so forth.

[0223] The pulsing schedule may be modified in any suitable manner, and certain pulses of electromagnetic radiation may be repeated at any suitable frequency, according to the needs of a user or computer-implemented program for a certain imaging procedure. For example, in an embodiment where surface tracking data generated based on the grid array 2706 is provided to a computer-implemented program for use in, for example, a robotic surgical procedure, the grid array 2706 may be pulsed more frequently than if the surface tracking data is provided to a user who is visualizing the scene during the imaging procedure. In such an embodiment where the surface tracking data is used for a robotic surgical procedure, the surface tracking data may need to be updated more frequently or may need to be exceedingly accurate such that the computer-implemented program may execute the robotic surgical procedure with precision and accuracy.

[0224] In an embodiment, the system 2700 is configured to generate an occupancy grid map comprising an array of cells divided into grids. The system 2700 is configured to store height values for each of the respective grid cells to determine a surface mapping of a three-dimensional environment in a light deficient environment.

[0225] FIGS. 28A and 28B illustrate a perspective view and a side view, respectively, of an implementation of a monolithic sensor 2800 having a plurality of pixel arrays for producing a three-dimensional image in accordance with the teachings and principles of the disclosure. Such an implementation may be desirable for three-dimensional image capture, wherein the two-pixel arrays 2802 and 2804 may be offset during use. In another implementation, a first pixel array 2802 and a second pixel array 2804 may be dedicated to receiving a predetermined range of wave lengths of electromagnetic radiation, wherein the first pixel array is dedicated to a different range of wavelength electromagnetic radiation than the second pixel array.

[0226] FIGS. 29A and 29B illustrate a perspective view and a side view, respectively, of an implementation of an imaging sensor 2900 built on a plurality of substrates. As illustrated, a plurality of pixel columns 2904 forming the pixel array are located on the first substrate 2902 and a plurality of circuit columns 2908 are located on a second substrate 2906. Also illustrated in the figure are the electrical connection and communication between one column of pixels to its associated or corresponding column of circuitry. In one implementation, an image sensor, which might otherwise be manufactured with its pixel array and supporting circuitry on a single, monolithic substrate/chip, may have the pixel array separated from all or a majority of the supporting circuitry. The disclosure may use at least two substrates/chips, which will be stacked together using three-dimensional stacking technology. The first 2902 of the 2902 substrates/chips may be processed using an image CMOS process. The first substrate/chip 2902 may be comprised either of a pixel array exclusively or a pixel array surrounded by limited circuitry. The second or subsequent substrate/chip 2906 may be processed using any process and does not have to be from an image CMOS process. The second substrate/chip 2906 may be, but is not limited to, a highly dense digital process to integrate a variety and number of functions in a very limited space or area on the substrate/chip, or a mixed-mode or analog process to integrate for example precise analog functions, or a RF process to implement wireless capability, or MEMS (Micro-Electro-Mechanical Systems) to integrate MEMS devices. The image CMOS substrate/chip 2902 may be stacked with the second or subsequent substrate/chip 2906 using any three-dimensional technique. The second substrate/chip 2906 may support most, or a majority, of the circuitry that would have otherwise been implemented in the first image CMOS chip 2902 (if implemented on a monolithic substrate/chip) as peripheral circuits and therefore have increased the overall system area while keeping the

pixel array size constant and optimized to the fullest extent possible. The electrical connection between the two substrates/chips may be done through interconnects, which may be wire bonds, bump and/or TSV (Through Silicon Via).

[0227] FIGS. 30A and 30B illustrate a perspective view and a side view, respectively, of an implementation of an imaging sensor 3000 having a plurality of pixel arrays for producing a three-dimensional image. The three-dimensional image sensor may be built on a plurality of substrates and may comprise the plurality of pixel arrays and other associated circuitry, wherein a plurality of pixel columns 3004a forming the first pixel array and a plurality of pixel columns 3004b forming a second pixel array are located on respective substrates 3002a and 3002b, respectively, and a plurality of circuit columns 3008a and 3008b are located on a separate substrate 3006. Also illustrated are the electrical connections and communications between columns of pixels to associated or corresponding column of circuitry.

[0228] The plurality of pixel arrays may sense information simultaneously and the information from the plurality of pixel arrays may be combined to generate a three-dimensional image. In an embodiment, an endoscopic imaging system includes two or more pixel arrays that can be deployed to generate three-dimensional imaging. The endoscopic imaging system may include an emitter for emitting pulses of electromagnetic radiation during a blanking period of the pixel arrays. The pixel arrays may be synced such that the optical black pixels are read (*i.e.*, the blanking period occurs) at the same time for the two or more pixel arrays. The emitter may emit pulses of electromagnetic radiation for charging each of the two or more pixel arrays. The two or more pixel arrays may read their respective charged pixels at the same time such that the readout periods for the two or more pixel arrays occur at the same time or at approximately the same time. In an embodiment, the endoscopic imaging system includes multiple emitters that are each individual synced with one or more pixel arrays of a plurality of pixel arrays. Information from a plurality of pixel arrays may be combined to generate three-dimensional image frames and video streams.

[0229] It will be appreciated that the teachings and principles of the disclosure may be used in a reusable device platform, a limited use device platform, a re-posable use device platform, or a single use/disposable device platform without departing from the scope of the disclosure. It will be appreciated that in a re-usable device platform an end-user is responsible for cleaning and sterilization of the device. In a limited use device platform, the device can be used for some specified amount of times before becoming inoperable. Typical new device is delivered sterile with additional uses requiring the end-user to clean and sterilize before additional uses. In a re-posable use device platform, a third-party may reprocess the device (e.g., cleans, packages and sterilizes) a single-use device for additional uses at a lower cost than a new unit. In a single use/disposable device platform a device is provided sterile to the operating room and used only once before being disposed of.

Examples

[0230] The following examples pertain to preferred features of further embodiments:

Example 1 is a system. The system includes an emitter for emitting pulses of electromagnetic radiation and an image sensor comprising a pixel array for sensing reflected electromagnetic radiation. The system includes a controller in electronic communication with the image sensor and the emitter configured to synchronize timing of the emitter and the image sensor to generate a plurality of exposure frames. The system is such that at least a portion of the pulses of electromagnetic radiation emitted by the emitter comprises one or more of: electromagnetic radiation having a wavelength from about 513 nm to about 545 nm; electromagnetic radiation having a wavelength from about 565 nm to

about 585 nm; electromagnetic radiation having a wavelength from about 900 nm to about 1000 nm; an excitation wavelength of electromagnetic radiation that causes a reagent to fluoresce; or a laser mapping pattern.

[0231] Example 2 is a system as in Example 1, wherein the pixel array comprises a plurality of pixels, and wherein a sensitivity of each of the plurality of pixels can be adjusted such that the pixel array comprises long exposure pixel and short exposure pixels.

[0232] Example 3 is a system as in any of Examples 1-2, wherein at least a portion of the plurality of exposure frames comprises a luminance exposure frame, a red chrominance exposure frame, and a blue chrominance exposure frame, and wherein: the luminance exposure frame comprises long exposure pixel data and short exposure pixel data; and the red chrominance exposure frame comprises long exposure pixel data and short exposure pixel data; and the blue chrominance exposure frame comprises long exposure pixel data and short exposure pixel data.

[0233] Example 4 is a system as in any of Examples 1-3, wherein the emitter modulates the pulses of electromagnetic radiation to provide luminance information according to color transformation coefficients that convert light energy from red, green, and blue light energy space to luminance, blue chrominance, and red chrominance light energy space.

[0234] Example 5 is a system as in any of Examples 1-4, wherein the emitter modulates the pulses of electromagnetic radiation to provide chrominance information according to color transformation coefficients that convert light energy from red, green, and blue light energy space to luminance, blue chrominance, and red chrominance light energy space.

[0235] Example 6 is a system as in any of Examples 1-5, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a blue chrominance pulse, a red chrominance pulse, a laser mapping pulse, and one or more of a hyperspectral pulse or a fluorescence pulse, wherein: the hyperspectral pulse comprises one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm; and the fluorescence pulse comprises one or more of electromagnetic radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm.

[0236] Example 7 is a system as in any of Examples 1-6, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a combined blue chrominance and red chrominance pulse, a laser mapping pulse, and one or more of a hyperspectral pulse or a fluorescence pulse, wherein: the hyperspectral pulse comprises one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm; and the fluorescence pulse comprises one or more of electromagnetic radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm.

[0237] Example 8 is a system as in any of Examples 1-7, wherein the controller is configured to generate image frames comprising data from a plurality of exposure frames, wherein a single image frame comprises data from a luminance exposure frame, a chrominance exposure frame, and one or more of a hyperspectral exposure frame, a fluorescence exposure frame, or a laser mapping exposure frame, wherein: the hyperspectral exposure frame is sensed by the pixel array in response to an emission of one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm; the fluorescence exposure frame is sensed by the pixel array in response to an emission of one or more of electromagnetic

radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm; and the laser mapping exposure frame is sensed by the pixel array in response to an emission of the laser mapping pattern.

[0238] Example 9 is a system as in any of Examples 1-8, wherein the image sensor is configured to generate a plurality of exposure frames, wherein each of the plurality of exposure frames corresponds to a pulse of electromagnetic radiation emitted by the emitter.

[0239] Example 10 is a system as in any of Examples 1-9, wherein the pixel array of the image sensor senses reflected electromagnetic radiation to generate the plurality of exposure frames during a readout period of the pixel array, wherein the readout period is a duration of time when active pixels in the pixel array are read.

[0240] Example 11 is a system as in any of Examples 1-10, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a red chrominance pulse, a blue chrominance pulse, and one or more of a hyperspectral pulse, a fluorescence pulse, or a laser mapping pulse, wherein the luminance pulse is represented in the pulsing pattern at least twice as often as the red chrominance pulse, the blue chrominance pulse, the hyperspectral pulse, the fluorescence pulse, or the laser mapping pulse.

[0241] Example 12 is a system as in any of Examples 1-11, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a laser mapping pulse for measuring a dimension, distance, or topology of a scene, wherein the laser mapping pulse comprises the laser mapping pattern and comprises a grid array or a dot array.

[0242] Example 13 is a system as in any of Examples 1-12, wherein the emitter is configured to emit, during a pulse duration, a plurality of sub-pulses of electromagnetic radiation having a sub-duration shorter than the pulse duration.

[0243] Example 14 is a system as in any of Examples 1-13, wherein one or more of the pulses of electromagnetic radiation emitted by the emitter comprise electromagnetic radiation emitted at two or more wavelengths simultaneously as a single pulse or a single sub-pulse.

[0244] Example 15 is a system as in any of Examples 1-14, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a fluorescence excitation emission that results in a fluorescence exposure frame created by the image sensor, and wherein the controller is configured to provide the fluorescence exposure frame to a corresponding fluorescence system that determines a location of a critical tissue structure within a scene based on the fluorescence exposure frame.

[0245] Example 16 is a system as in any of Examples 1-15, wherein the fluorescence excitation emission comprises: the electromagnetic radiation having the wavelength from about 770 nm to about 790 nm; or the electromagnetic radiation having the wavelength from about 795 nm to about 815 nm.

[0246] Example 17 is a system as in any of Examples 1-16, wherein the controller is further configured to: receive the location of the critical tissue structure from the corresponding fluorescence system; generate an overlay frame comprising the location of the critical tissue structure; and combine the overlay frame with a color image frame depicting the scene to indicate the location of the critical tissue structure within the scene.

[0247] Example 18 is a system as in any of Examples 1-17, wherein sensing the reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, and wherein the controller is further configured to: provide the laser mapping exposure frame to a corresponding laser mapping system that determines a topology of the scene

and/or dimensions of one or more objects within the scene; provide the location of the critical tissue structure to the corresponding laser mapping system; and receive a topology and/or dimension of the critical tissue structure from the corresponding laser mapping system.

[0248] Example 19 is a system as in any of Examples 1-18, wherein the critical structure comprises one or more of a nerve, a ureter, a blood vessel, an artery, a blood flow, or a tumor.

[0249] Example 20 is a system as in any of Examples 1-19, wherein the controller is configured to synchronize timing of the pulses of electromagnetic radiation during a blanking period of the image sensor, wherein the blanking period corresponds to a time between a readout of a last row of active pixels in the pixel array and a beginning of a next subsequent readout of active pixels in the pixel array.

[0250] Example 21 is a system as in any of Examples 1-20, wherein two or more pulses of electromagnetic radiation emitted by the emitter result in two or more instances of reflected electromagnetic radiation that are sensed by the pixel array to generate two or more exposure frames that are combined to form an image frame.

[0251] Example 22 is a system as in any of Examples 1-21, wherein the image sensor comprises a first image sensor and a second image sensor such that the image sensor can generate a three-dimensional image.

[0252] Example 23 is a system as in any of Examples 1-22, wherein the emitter is configured to emit a sequence of pulses of electromagnetic radiation repeatedly sufficient for generating a video stream comprising a plurality of image frames, wherein each image frame in the video stream comprises data from a plurality of exposure frames, and wherein each of the exposure frames corresponds to a pulse of electromagnetic radiation.

[0253] Example 24 is a system as in any of Examples 1-23, wherein the pulses of electromagnetic radiation are emitted in a pattern of varying wavelengths of electromagnetic radiation, and wherein the emitter repeats the pattern of varying wavelengths of electromagnetic radiation.

[0254] Example 25 is a system as in any of Examples 1-24, wherein at least a portion of the pulses of electromagnetic radiation comprise a luminance emission, a red chrominance emission, a blue chrominance emission, and a laser mapping emission such that reflected electromagnetic radiation sensed by the pixel array corresponding to each of the luminance emission, the red chrominance emission, the blue chrominance emission, and the laser mapping emission can be processed to generate a YCbCr image frame comprising an overlay of laser mapping data.

[0255] Example 26 is a system as in any of Examples 1-25, wherein sensing reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, wherein the laser mapping exposure frame comprises information for determining real time measurements comprising one or more of: a distance from an endoscope to an object; an angle between an endoscope and the object; or surface topology information about the object.

[0256] Example 27 is a system as in any of Examples 1-26, wherein the laser mapping exposure frame comprises information for determining the real time measurements to an accuracy of less than 10 centimeters.

[0257] Example 28 is a system as in any of Examples 1-27, wherein the laser mapping exposure frame comprises information for determining the real time measurements to an accuracy of less than one millimeter.

[0258] Example 29 is a system as in any of Examples 1-28, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter comprises a plurality of tool-specific laser mapping patterns for each of a plurality of tools within a scene.

[0259] Example 30 is a system as in any of Examples 1-29, wherein the laser mapping pattern emitted by the emitter comprises a first output and a second output that are independent from one another, wherein the first output is for light illumination and the second output is for tool tracking.

[0260] Example 31 is a system as in any of Examples 1-30, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a hyperspectral emission for eliciting a spectral response, wherein the hyperspectral emission results in a hyperspectral exposure frame created by the image sensor, and wherein the controller is configured to provide the hyperspectral exposure frame to a corresponding hyperspectral system that determines a location of a critical tissue structure within a scene based on the hyperspectral exposure frame.

[0261] Example 32 is a system as in any of Examples 1-31, wherein the hyperspectral emission comprises one or more of: the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm; the electromagnetic radiation having the wavelength from about 565 nm to about 585 nm; or the electromagnetic radiation having the wavelength from about 900 nm to about 1000 nm;

[0262] Example 33 is a system as in any of Examples 1-32, wherein the controller is further configured to: receive the location of the critical tissue structure from the corresponding hyperspectral system; generate an overlay frame comprising the location of the critical tissue structure; and combine the overlay frame with a color image frame depicting the scene to indicate the location of the critical tissue structure within the scene.

[0263] Example 34 is a system as in any of Examples 1-33, wherein sensing the reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, and wherein the controller is further configured to: provide the laser mapping exposure frame to a corresponding laser mapping system that determines a topology of the scene and/or dimensions of one or more objects within the scene; provide the location of the critical tissue structure to the corresponding laser mapping system; and receive a topology and/or dimension of the critical tissue structure from the corresponding laser mapping system.

[0264] Example 35 is a system as in any of Examples 1-34, wherein the critical structure comprises one or more of a nerve, a ureter, a blood vessel, an artery, a blood flow, or a tumor.

[0265] Example 36 is a system as in any of Examples 1-35, wherein at least a portion of the pulses of electromagnetic radiation comprise a luminance emission, a red chrominance emission, a blue chrominance emission, and one or more of a hyperspectral emission, a fluorescence emission, or a laser mapping emission such that reflected electromagnetic radiation sensed by the pixel array corresponding to each of the luminance emission, the red chrominance emission, the blue chrominance emission, and the one or more of the hyperspectral emission, the fluorescence emission, or the laser mapping emission can be processed to generate a YCbCr image frame comprising an overlay of one or more of hyperspectral imaging data, fluorescence imaging data, or laser mapping data.

[0266] Example 37 is a system as in any of Examples 1-36, further comprising a filter that filters electromagnetic radiation having a wavelength from about 770 nm to about 790 nm.

[0267] Example 38 is a system as in any of Examples 1-37, further comprising a filter that filters electromagnetic radiation having a wavelength from about 795 nm to about 815 nm.

[0268] It will be appreciated that various features disclosed herein provide significant advantages and advancements in the art. The following claims are exemplary of some of those features.

[0269] In the foregoing Detailed Description of the Disclosure, various features of the disclosure are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed disclosure requires more features than are expressly recited in each claim. Rather, inventive aspects lie in less than all features of a single foregoing disclosed embodiment.

[0270] It is to be understood that any features of the above-described arrangements, examples, and embodiments may be combined in a single embodiment comprising a combination of features taken from any of the disclosed arrangements, examples, and embodiments.

[0271] It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the disclosure. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the disclosure and the appended claims are intended to cover such modifications and arrangements.

[0272] Thus, while the disclosure has been shown in the drawings and described above with particularity and detail, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

[0273] Further, where appropriate, functions described herein can be performed in one or more of: hardware, software, firmware, digital components, or analog components. For example, one or more application specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) can be programmed to carry out one or more of the systems and procedures described herein. Certain terms are used throughout the following description and claims to refer to particular system components. As one skilled in the art will appreciate, components may be referred to by different names. This document does not intend to distinguish between components that differ in name, but not function.

[0274] The foregoing description has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. Further, it should be noted that any or all the aforementioned alternate implementations may be used in any combination desired to form additional hybrid implementations of the disclosure.

[0275] Further, although specific implementations of the disclosure have been described and illustrated, the disclosure is not to be limited to the specific forms or arrangements of parts so described and illustrated. The scope of the disclosure is to be defined by the claims appended hereto, any future claims submitted here and in different applications, and their equivalents.

CLAIMS

What is claimed is:

1. A system comprising:

an emitter for emitting pulses of electromagnetic radiation;

an image sensor comprising a pixel array for sensing reflected electromagnetic radiation; and

a controller in electronic communication with the image sensor and the emitter configured to synchronize timing of the emitter and the image sensor to generate a plurality of exposure frames;

wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter comprises one or more of:

electromagnetic radiation having a wavelength from about 513 nm to about 545 nm;

electromagnetic radiation having a wavelength from about 565 nm to about 585 nm;

electromagnetic radiation having a wavelength from about 900 nm to about 1000 nm;

an excitation wavelength of electromagnetic radiation that causes a reagent to fluoresce; or

a laser mapping pattern.

2. The system of claim 1, wherein the pixel array comprises a plurality of pixels, and wherein a sensitivity of each of the plurality of pixels can be adjusted such that the pixel array comprises long exposure pixels and short exposure pixels.

3. The system of claim 1, wherein at least a portion of the plurality of exposure frames comprises a luminance exposure frame, a red chrominance exposure frame, and a blue chrominance exposure frame, and wherein:

the luminance exposure frame comprises long exposure pixel data and short exposure pixel data; and

the red chrominance exposure frame comprises long exposure pixel data and short exposure pixel data; and

the blue chrominance exposure frame comprises long exposure pixel data and short exposure pixel data.

4. The system of claim 1, wherein the emitter modulates the pulses of electromagnetic radiation to provide luminance information according to color transformation coefficients that convert light energy from red, green, and blue light energy space to luminance, blue chrominance, and red chrominance light energy space.

5. The system of claim 1, wherein the emitter modulates the pulses of electromagnetic radiation to provide chrominance information according to color transformation coefficients that convert light energy from red, green, and blue light energy space to luminance, blue chrominance, and red chrominance light energy space.

6. The system of claim 1, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a blue chrominance pulse, a red chrominance pulse, a laser mapping pulse, and one or more of a hyperspectral pulse or a fluorescence pulse, wherein:

the hyperspectral pulse comprises one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm; and

the fluorescence pulse comprises one or more of electromagnetic radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm.

7. The system of claim 1, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a combined blue chrominance and red chrominance pulse, a laser mapping pulse, and one or more of a hyperspectral pulse or a fluorescence pulse, wherein:

the hyperspectral pulse comprises one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm; and

the fluorescence pulse comprises one or more of electromagnetic radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm.

8. The system of claim 1, wherein the controller is configured to generate image frames comprising data from a plurality of exposure frames, wherein a single image frame comprises data from a luminance exposure frame, a chrominance exposure frame, and one or more of a hyperspectral exposure frame, a fluorescence exposure frame, or a laser mapping exposure frame, wherein:

the hyperspectral exposure frame is sensed by the pixel array in response to an emission of one or more of the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm, or from about 565 nm to about 585 nm, or from about 900 nm to about 1000 nm;

the fluorescence exposure frame is sensed by the pixel array in response to an emission of one or more of electromagnetic radiation having a wavelength from about 770 nm to about 790 nm or from about 795 nm to about 815 nm; and

the laser mapping exposure frame is sensed by the pixel array in response to an emission of the laser mapping pattern.

9. The system of claim 1, wherein the image sensor is configured to generate a plurality of exposure frames, wherein each of the plurality of exposure frames corresponds to a pulse of electromagnetic radiation emitted by the emitter.

10. The system of claim 9, wherein the pixel array of the image sensor senses reflected electromagnetic radiation to generate the plurality of exposure frames during a readout period of the pixel array, wherein the readout period is a duration of time when active pixels in the pixel array are read.

11. The system of claim 1, wherein the pulses of electromagnetic radiation are emitted according to a pulsing pattern comprising a luminance pulse, a red chrominance pulse, a blue chrominance pulse, and one or more of a hyperspectral pulse, a fluorescence pulse, or a laser mapping pulse, wherein the luminance pulse is represented in the pulsing pattern at least twice as often as the red chrominance pulse, the blue chrominance pulse, the hyperspectral pulse, the fluorescence pulse, or the laser mapping pulse.

12. The system of claim 1, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a laser mapping pulse for measuring a dimension, distance, or topology of a scene, wherein the laser mapping pulse comprises the laser mapping pattern and comprises a grid array or a dot array.

13. The system of claim 1, wherein the emitter is configured to emit, during a pulse duration, a plurality of sub-pulses of electromagnetic radiation having a sub-duration shorter than the pulse duration.

14. The system of claim 1, wherein one or more of the pulses of electromagnetic radiation emitted by the emitter comprises electromagnetic radiation emitted at two or more wavelengths simultaneously as a single pulse or a single sub-pulse.

15. The system of claim 1, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a fluorescence excitation emission that results in a fluorescence exposure frame created by the image sensor, and wherein the controller is configured to provide the fluorescence exposure frame to a corresponding fluorescence system that determines a location of a critical tissue structure within a scene based on the fluorescence exposure frame.

16. The system of claim 15, wherein the fluorescence excitation emission comprises one or more of:

electromagnetic radiation having a wavelength from about 770 nm to about 790 nm; or

the electromagnetic radiation having the wavelength from about 795 nm to about 815 nm.

17. The system of claim 16, wherein the controller is further configured to:

receive the location of the critical tissue structure from the corresponding fluorescence system;

generate an overlay frame comprising the location of the critical tissue structure; and

combine the overlay frame with a color image frame depicting the scene to indicate the location of the critical tissue structure within the scene.

18. The system of claim 17, wherein sensing the reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, and wherein the controller is further configured to:

provide the laser mapping exposure frame to a corresponding laser mapping system that determines a topology of the scene and/or dimensions of one or more objects within the scene;

provide the location of the critical tissue structure to the corresponding laser mapping system; and

receive a topology and/or dimension of the critical tissue structure from the corresponding laser mapping system.

19. The system of claim 18, wherein the critical structure comprises one or more of a nerve, a ureter, a blood vessel, an artery, a blood flow, or a tumor.

20. The system of claim 1, wherein at least a portion of the pulses of electromagnetic radiation emitted by the emitter is a hyperspectral emission for eliciting a spectral response, wherein the hyperspectral emission results in a hyperspectral exposure frame created by the image sensor, and wherein the controller is configured to provide the hyperspectral exposure frame to a corresponding hyperspectral system that determines a location of a critical tissue structure within a scene based on the hyperspectral exposure frame.

21. The system of claim 20, wherein the hyperspectral emission comprises one or more of:

the electromagnetic radiation having the wavelength from about 513 nm to about 545 nm;

the electromagnetic radiation having the wavelength from about 565 nm to about 585 nm; or

the electromagnetic radiation having the wavelength from about 900 nm to about 1000 nm.

22. The system of claim 21, wherein the controller is further configured to:

receive the location of the critical tissue structure from the corresponding hyperspectral system;

generate an overlay frame comprising the location of the critical tissue structure; and

combine the overlay frame with a color image frame depicting the scene to indicate the location of the critical tissue structure within the scene.

23. The system of claim 22, wherein sensing the reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, and wherein the controller is further configured to:

provide the laser mapping exposure frame to a corresponding laser mapping system that determines a topology of the scene and/or dimensions of one or more objects within the scene;

provide the location of the critical tissue structure to the corresponding laser mapping system; and

receive a topology and/or dimension of the critical tissue structure from the corresponding laser mapping system.

24. The system of claim 23, wherein the critical structure comprises one or more of a nerve, a ureter, a blood vessel, an artery, a blood flow, or a tumor.

25. The system of claim 1, wherein the controller is configured to synchronize timing of the pulses of electromagnetic radiation during a blanking period of the image sensor, wherein the blanking period corresponds to a time between a readout of a last row of active pixels in the pixel array and a beginning of a next subsequent readout of active pixels in the pixel array.

26. The system of claim 1, wherein two or more pulses of electromagnetic radiation emitted by the emitter result in two or more instances of reflected electromagnetic radiation that are sensed by the pixel array to generate two or more exposure frames that are combined to form an image frame.

27. The system of claim 1, wherein the image sensor comprises a first image sensor and a second image sensor such that the image sensor can generate a three-dimensional image.

28. The system of claim 1, wherein at least a portion of the pulses of electromagnetic radiation comprise a luminance emission, a red chrominance emission, a blue chrominance emission, and one or more of a hyperspectral emission, a fluorescence emission, or a laser mapping emission such that reflected electromagnetic radiation sensed by the pixel array corresponding to each of the luminance emission, the red chrominance emission, the blue chrominance emission, and the one or more of the hyperspectral emission, the fluorescence emission, or the laser mapping emission can be processed to generate a YCbCr image frame comprising an overlay of one or more of hyperspectral imaging data, fluorescence imaging data, or laser mapping data.

29. The system of claim 1, wherein sensing reflected electromagnetic radiation by the pixel array comprises generating a laser mapping exposure frame by sensing reflected electromagnetic radiation resulting from the emitter pulsing the laser mapping pattern, wherein the laser mapping exposure frame comprises information for determining real time measurements comprising one or more of:

a distance from an endoscope to an object;

an angle between an endoscope and the object; or

surface topology information about the object.

30. The system of claim 1, wherein the laser mapping pattern emitted by the emitter comprises a first output and a second output that are independent from one another, wherein the first output is for light illumination and the second output is for tool tracking.

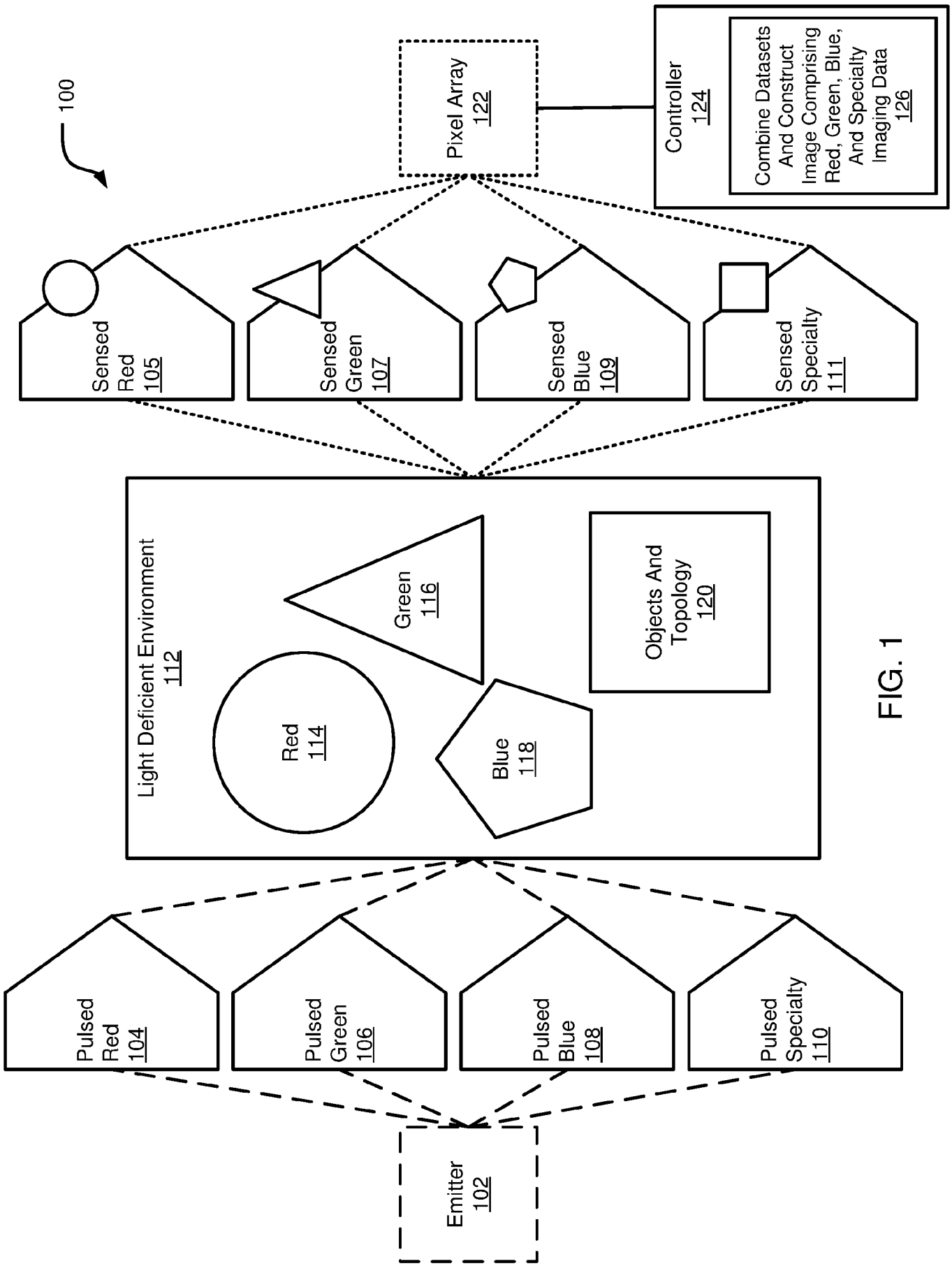

100
Pixel Array
122
Controller
124
Combine Datasets And Construct Image Comprising Red, Green, Blue, And Specialty Imaging Data
126
Sensed Red
105
Sensed Green
107
Sensed Blue
109
Sensed Specialty
111
Light Deficient Environment
112
Green
116
Red
114
Blue
118
Objects And Topology
120
Pulsed Red
104
Pulsed Green
106
Pulsed Blue
108
Pulsed Specialty
110
Emitter
102

FIG. 1

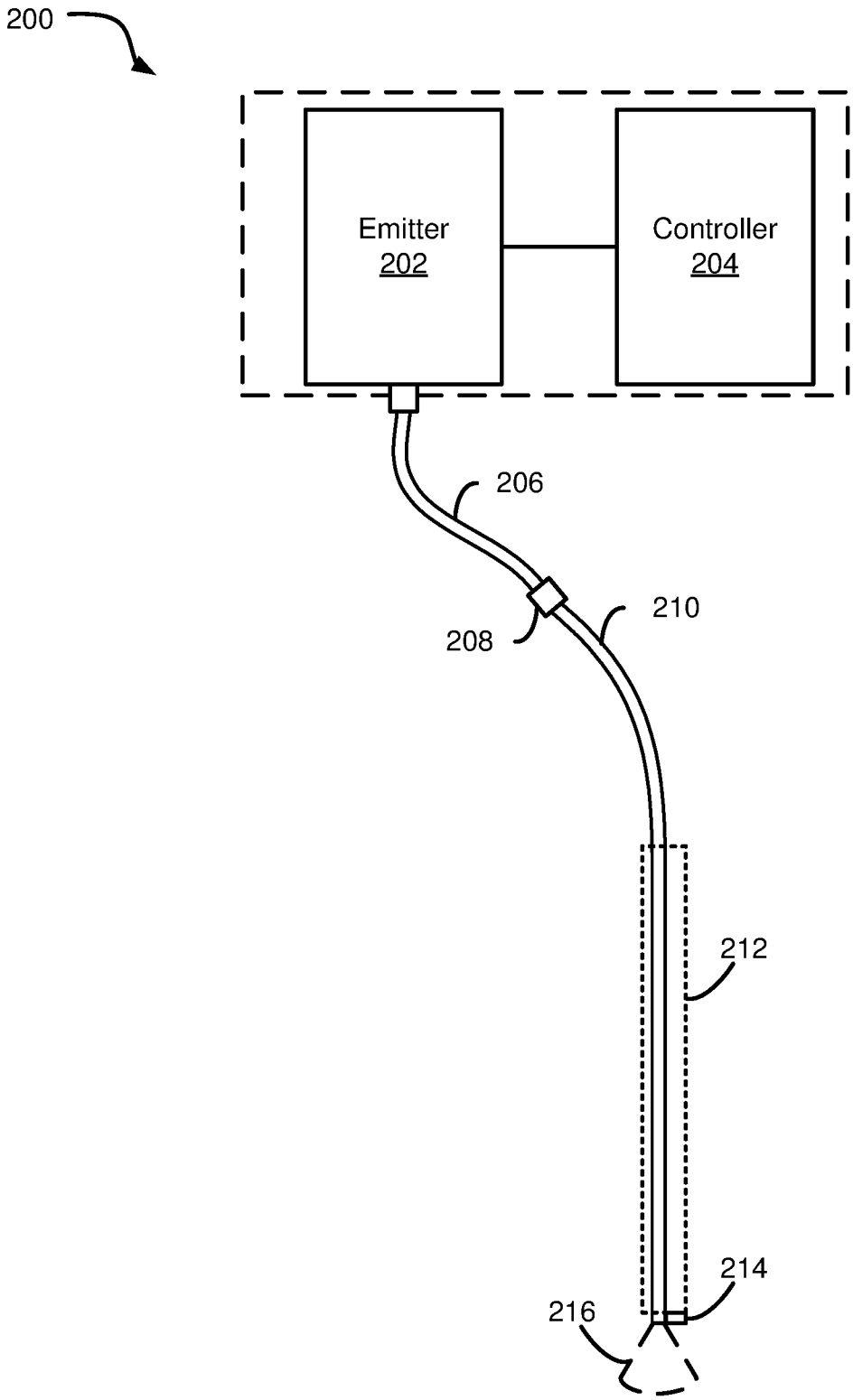


FIG. 2

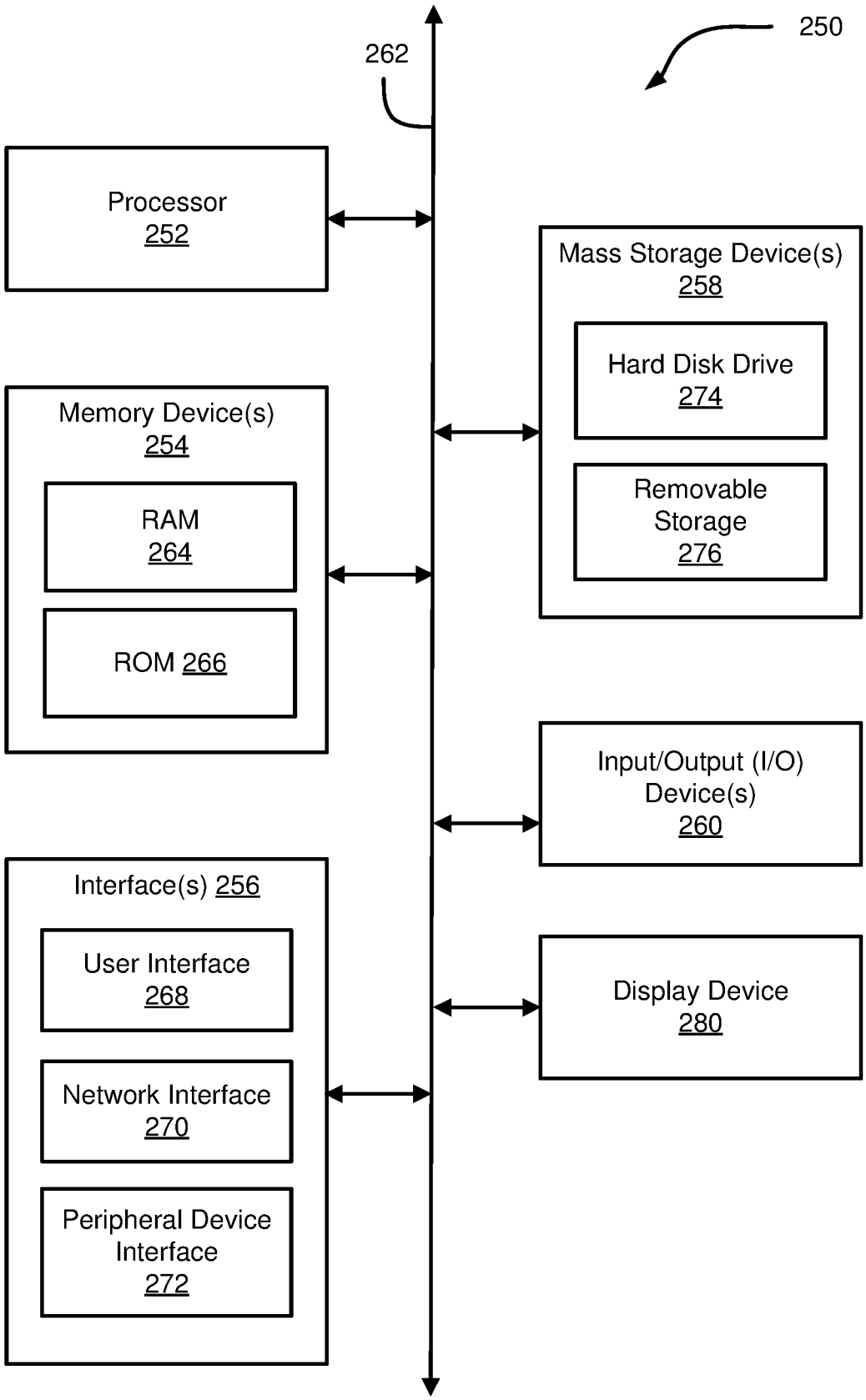

250
262
Processor
252
Mass Storage Device(s)
258
Hard Disk Drive
274
Removable
Storage
276
Memory Device(s)
254
RAM
264
ROM 266
Input/Output (I/O)
Device(s)
260
Interface(s) 256
User Interface
268
Display Device
280
Network Interface
270
Peripheral Device
Interface
272

FIG. 2A

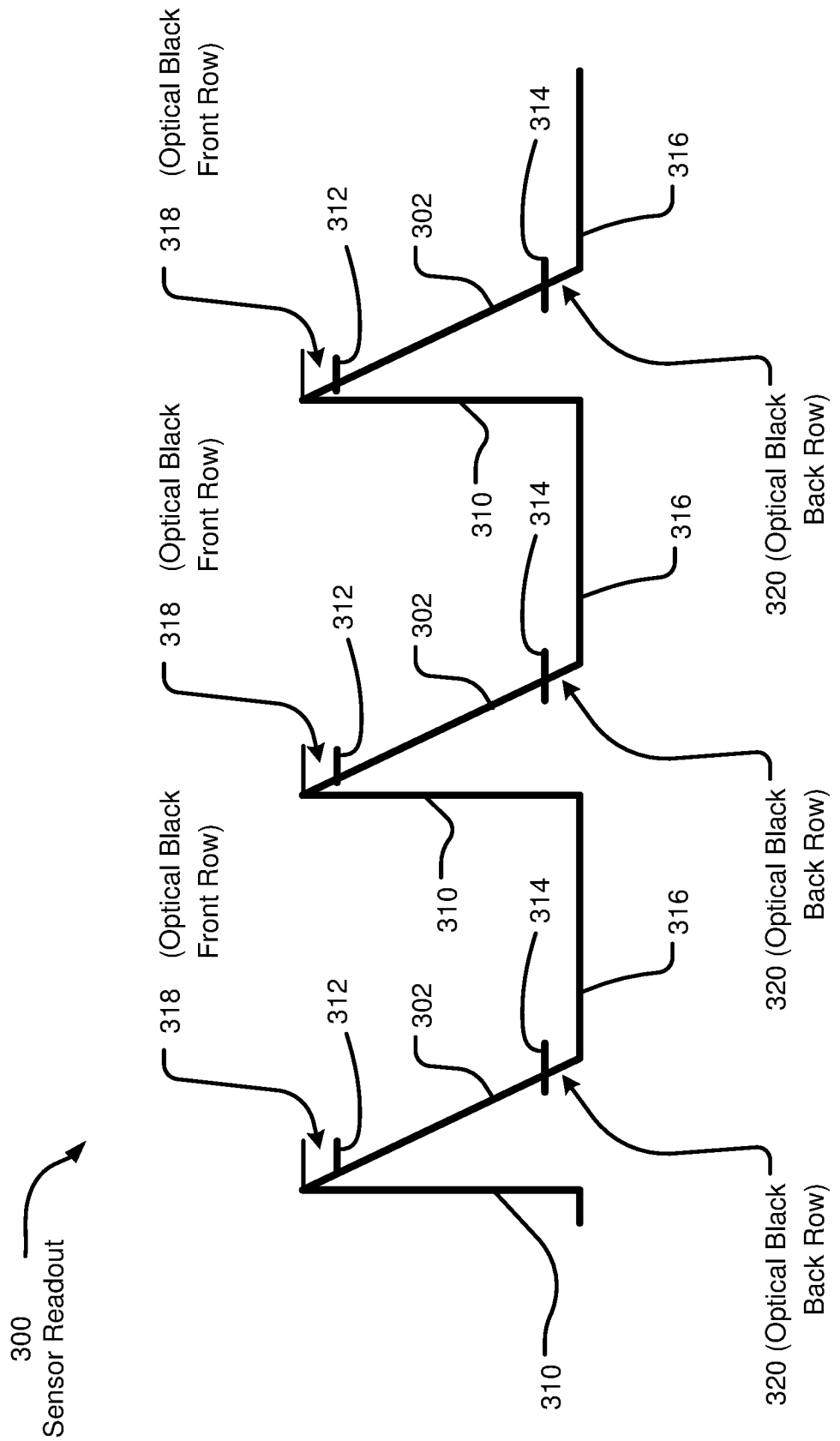

300
Sensor Readout
318 (Optical Black Front Row)
312
302
314
316
310
320 (Optical Black Back Row)

FIG. 3A

FIG. 3B

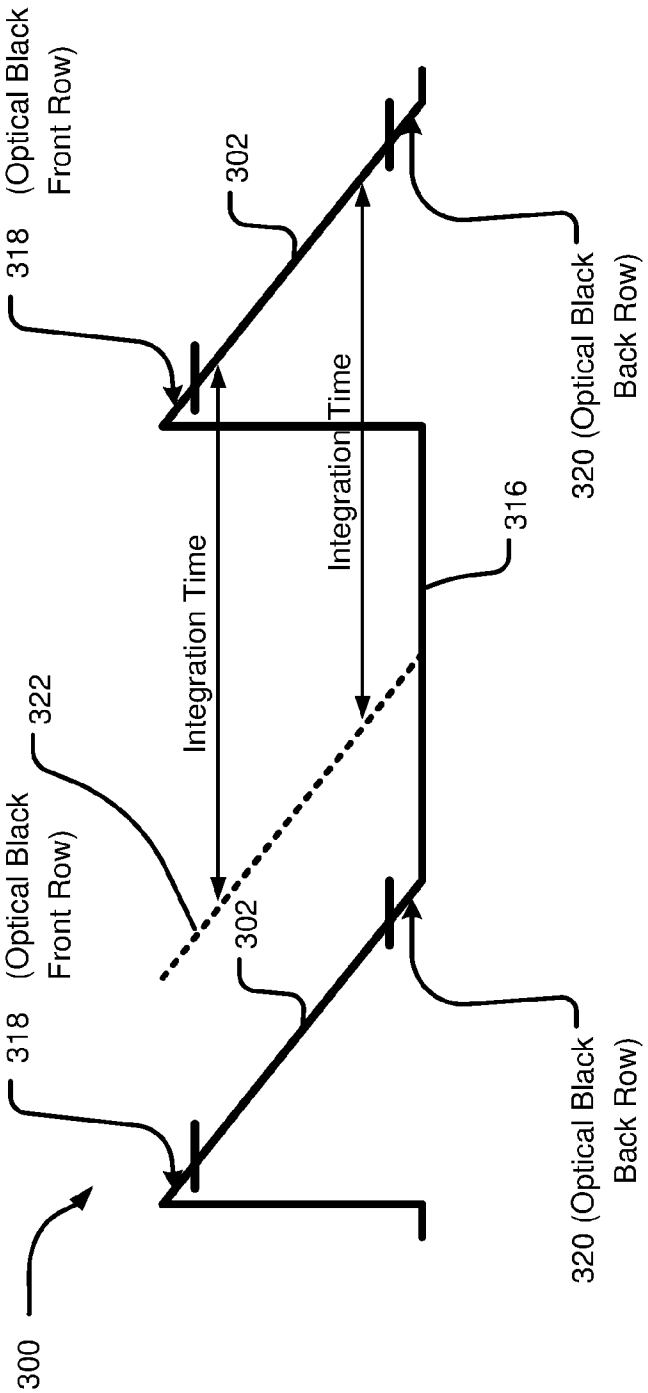
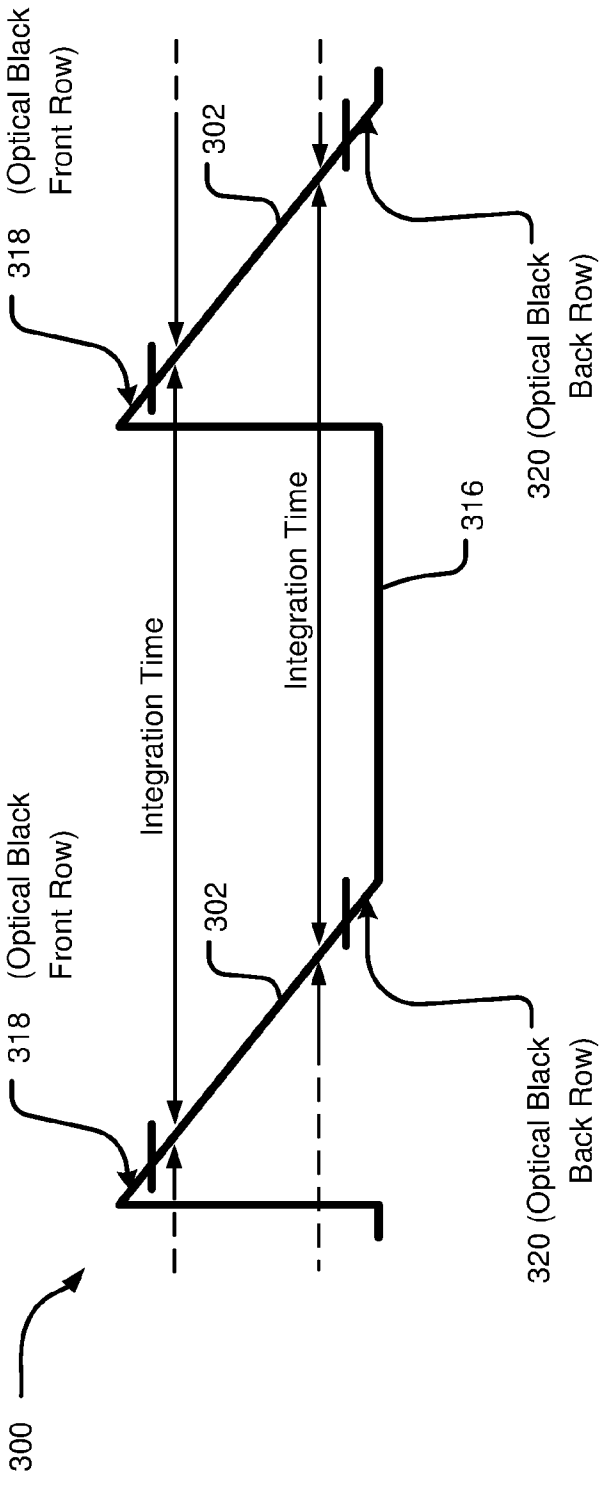

300
318 (Optical Black Front Row)
302
320 (Optical Black Back Row)
316
Integration Time
Integration Time
322
318 (Optical Black Front Row)
302
320 (Optical Black Back Row)

FIG. 3C


300
318 (Optical Black Front Row)
302
320 (Optical Black Back Row)
316
Integration Time
Integration Time
318 (Optical Black Front Row)
302
320 (Optical Black Back Row)

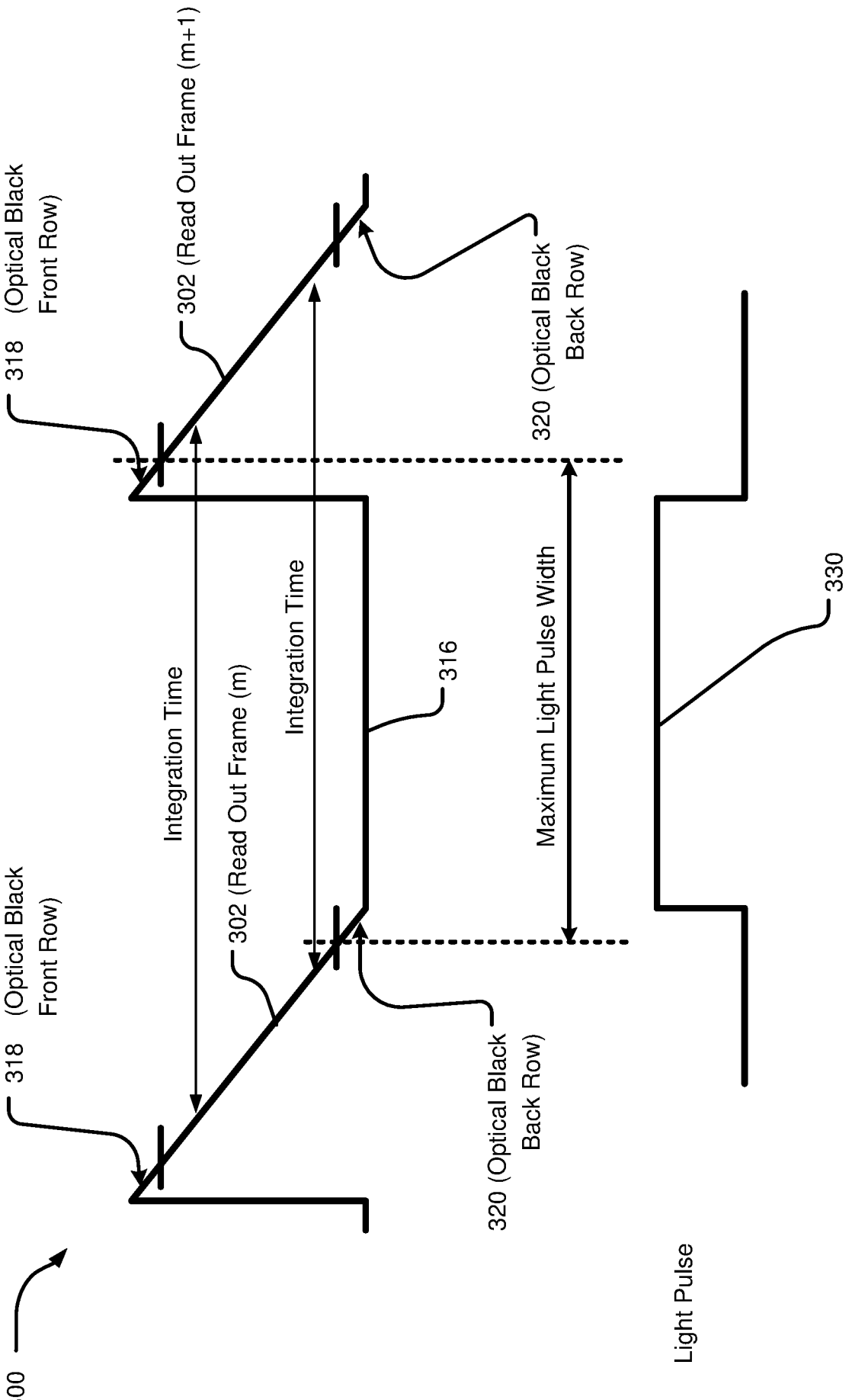

300
318 (Optical Black Front Row)
302 (Read Out Frame (m+1)
320 (Optical Black Back Row)
Integration Time
302 (Read Out Frame (m)
Integration Time
316
Maximum Light Pulse Width
318 (Optical Black Front Row)
320 (Optical Black Back Row)
330
Light Pulse

FIG. 3D

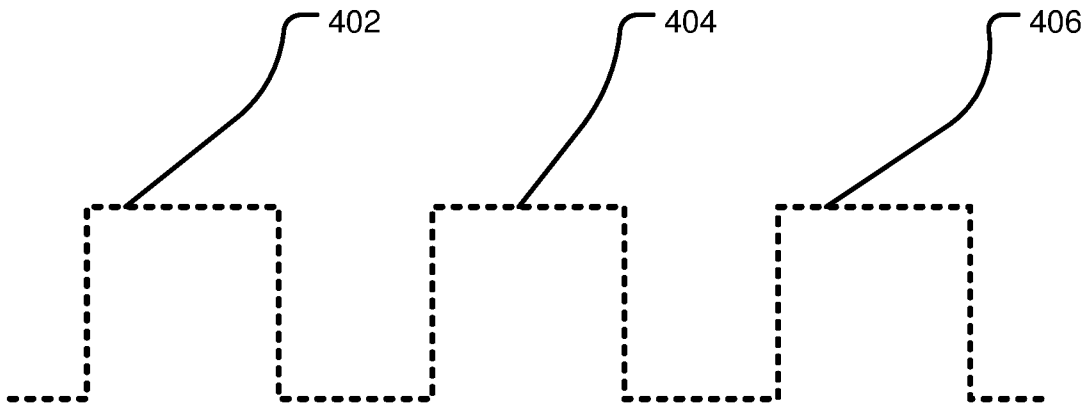


FIG. 4A

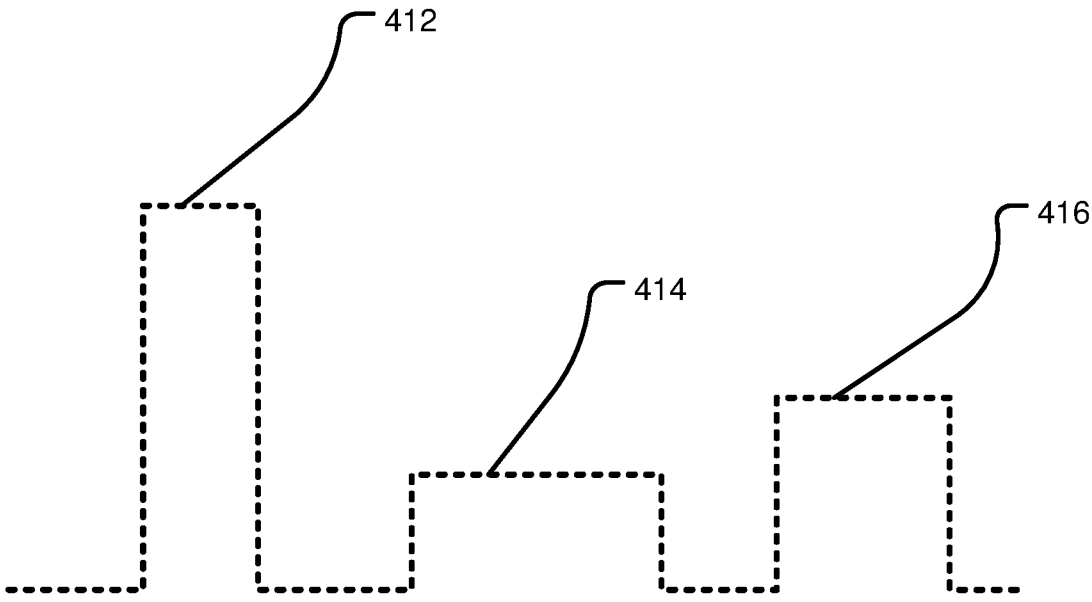


FIG. 4B

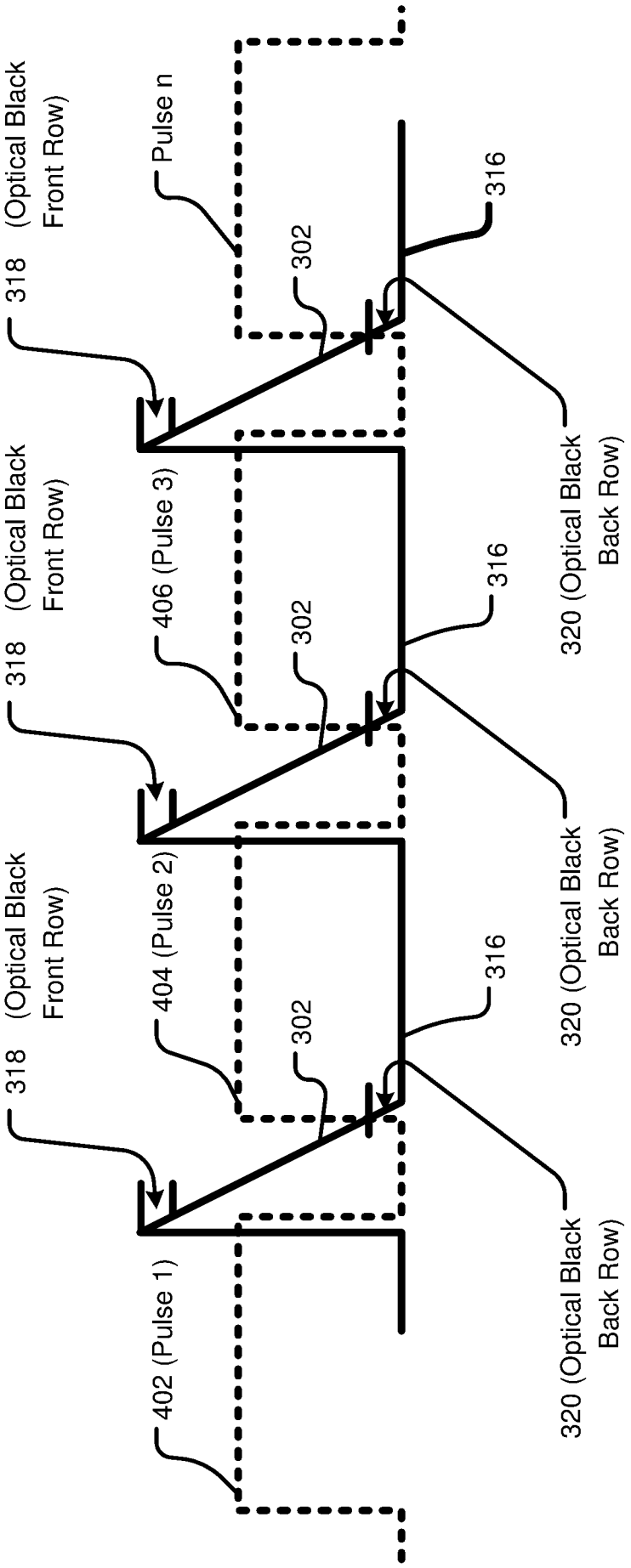

318 (Optical Black Front Row)
Pulse n
316
302
320 (Optical Black Back Row)
318 (Optical Black Front Row)
406 (Pulse 3)
316
302
320 (Optical Black Back Row)
318 (Optical Black Front Row)
404 (Pulse 2)
316
302
320 (Optical Black Back Row)
402 (Pulse 1)

FIG. 5

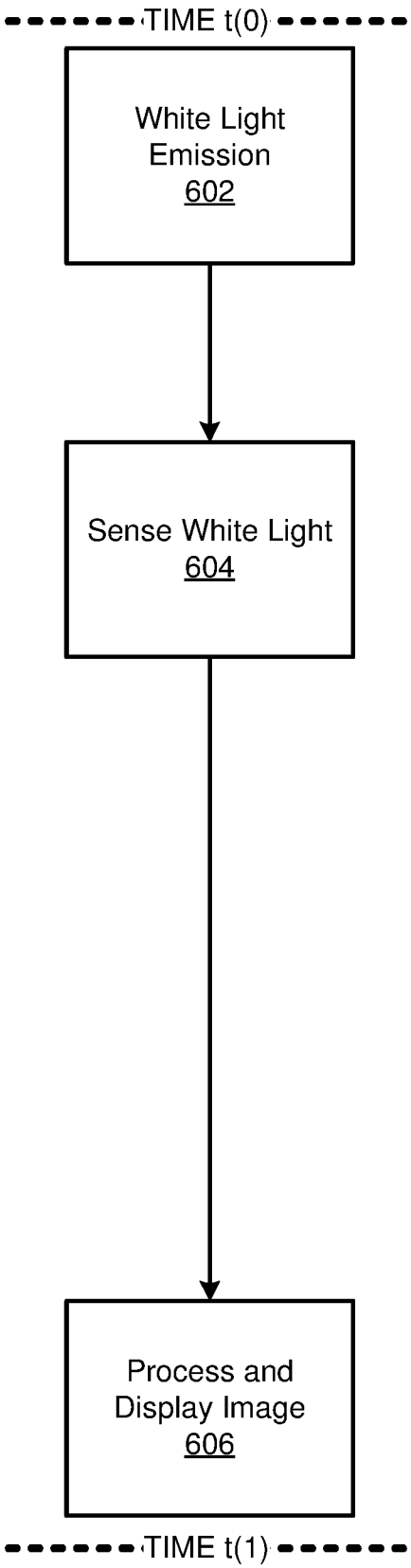


FIG. 6A
(Prior Art)

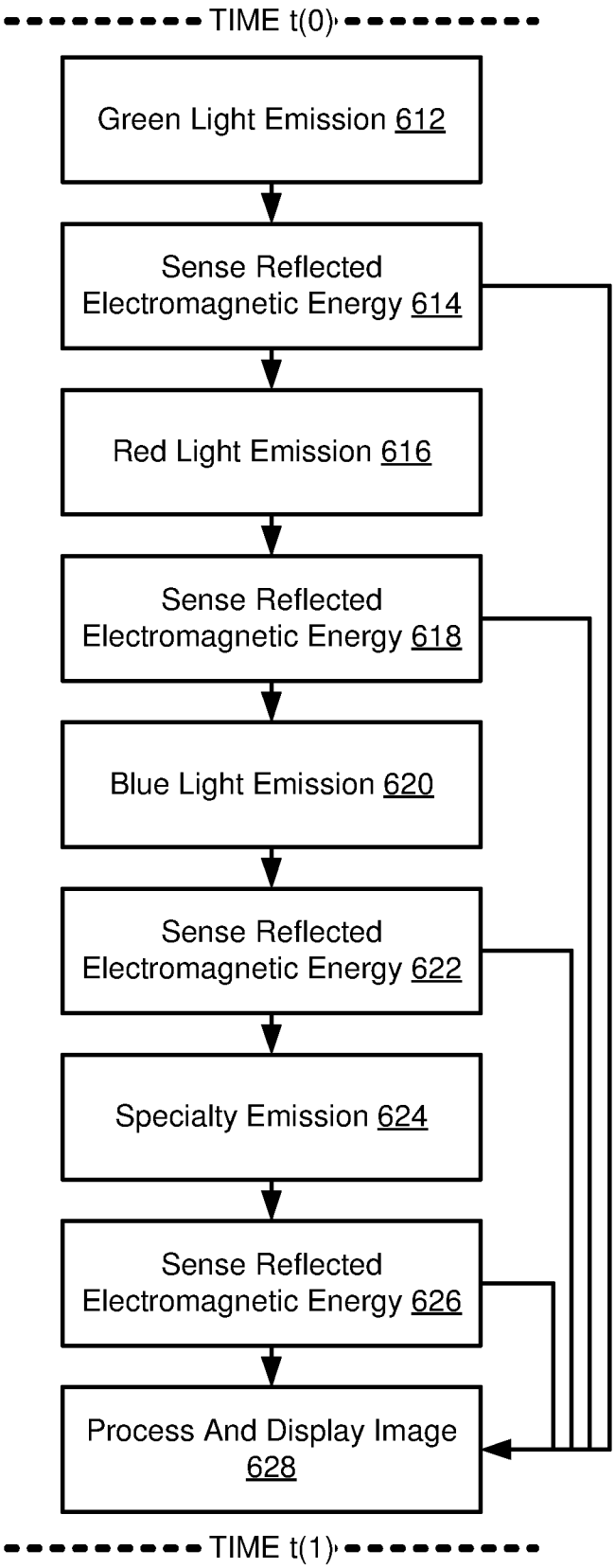


FIG. 6B

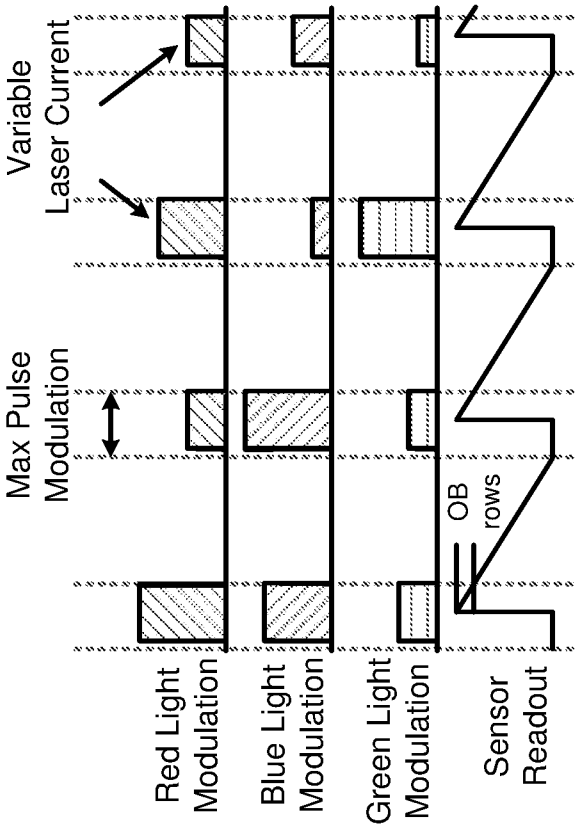


FIG. 7B

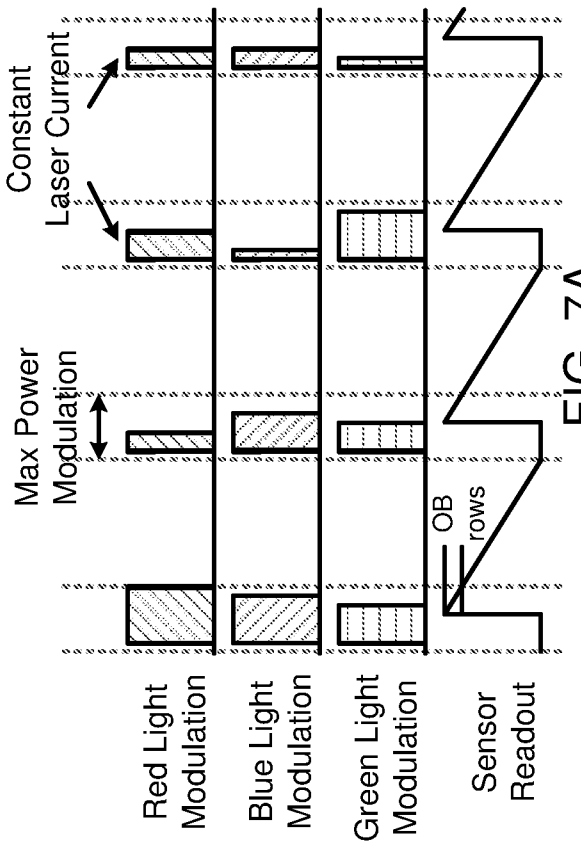


FIG. 7A

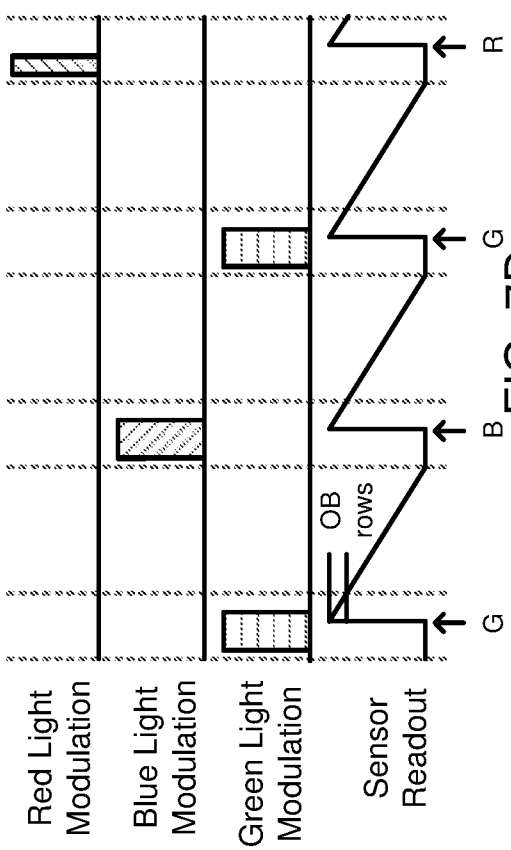


FIG. 7D

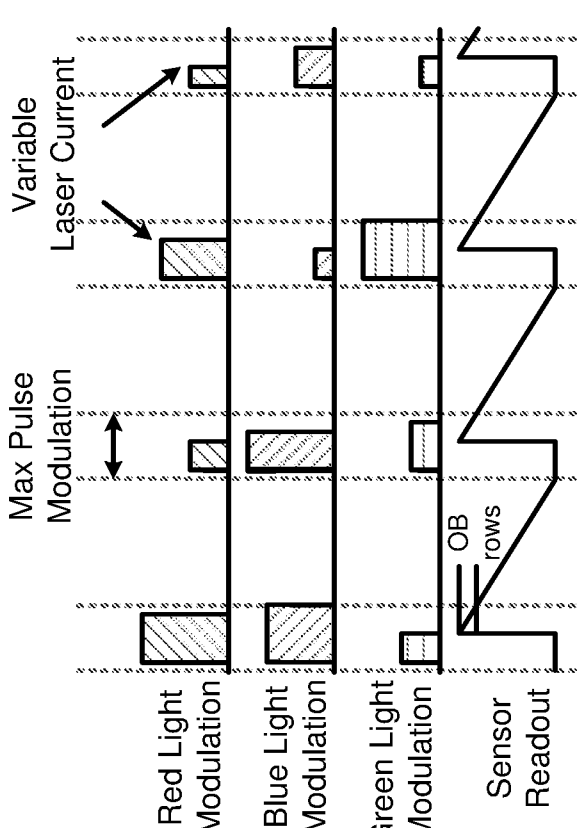


FIG. 7C

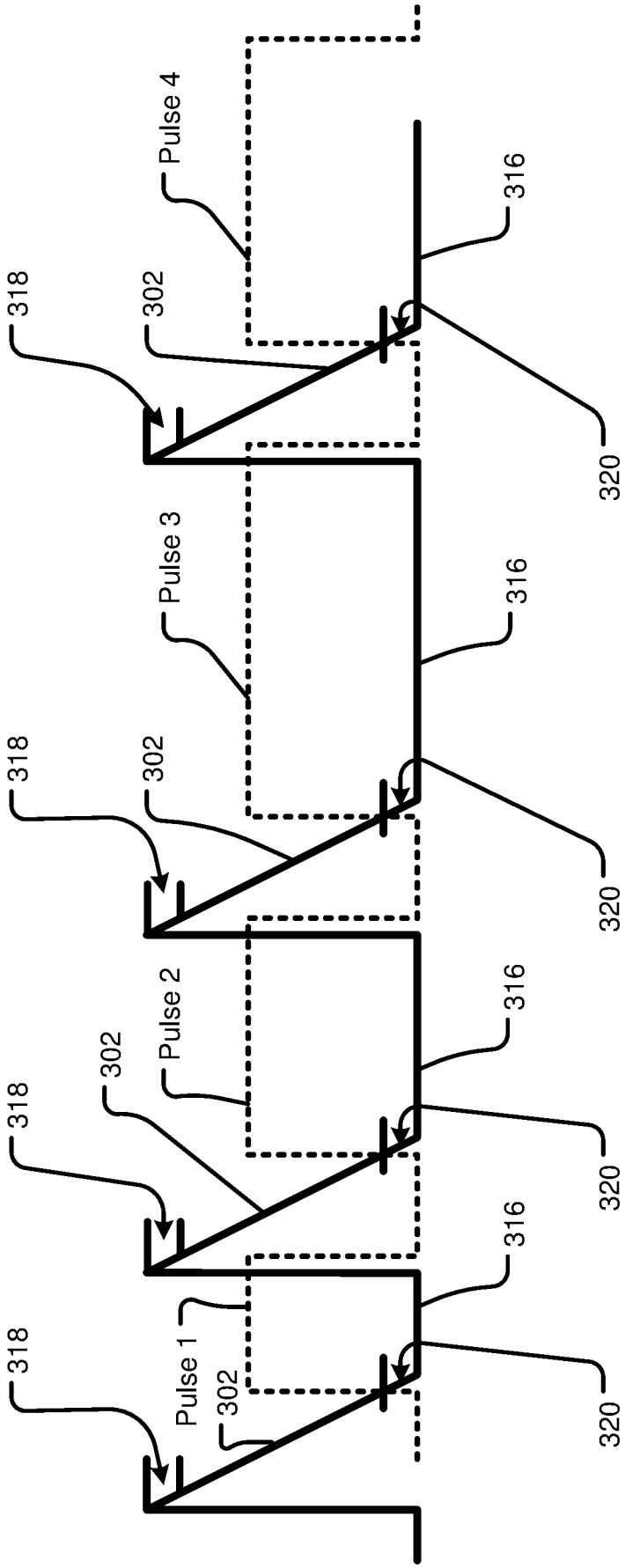

Pulse 4
316
318
302
320
Pulse 3
316
318
302
320
Pulse 2
316
302
318
320
316
Pulse 1
318
302
320

FIG. 7E

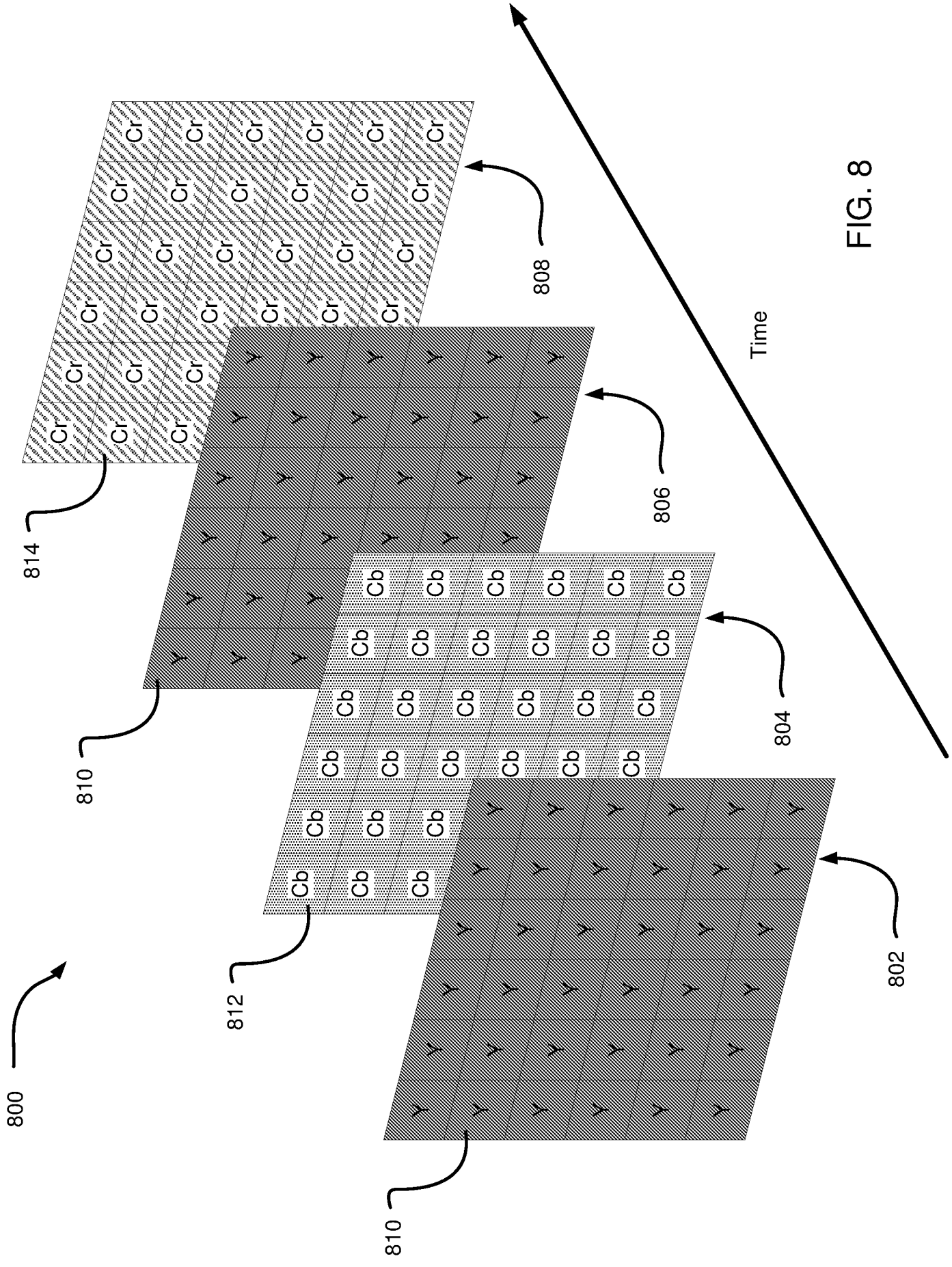


FIG. 8

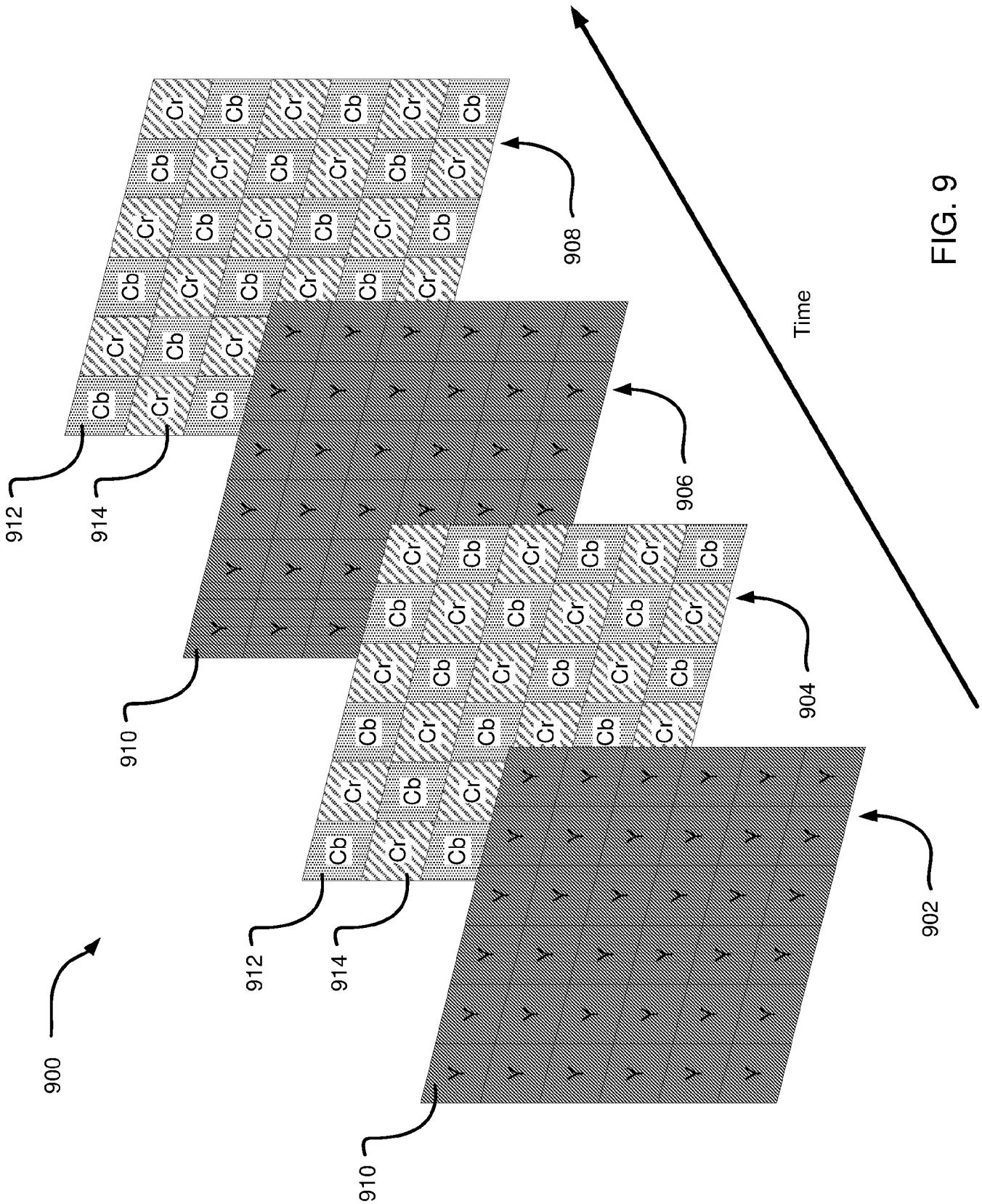


FIG. 9

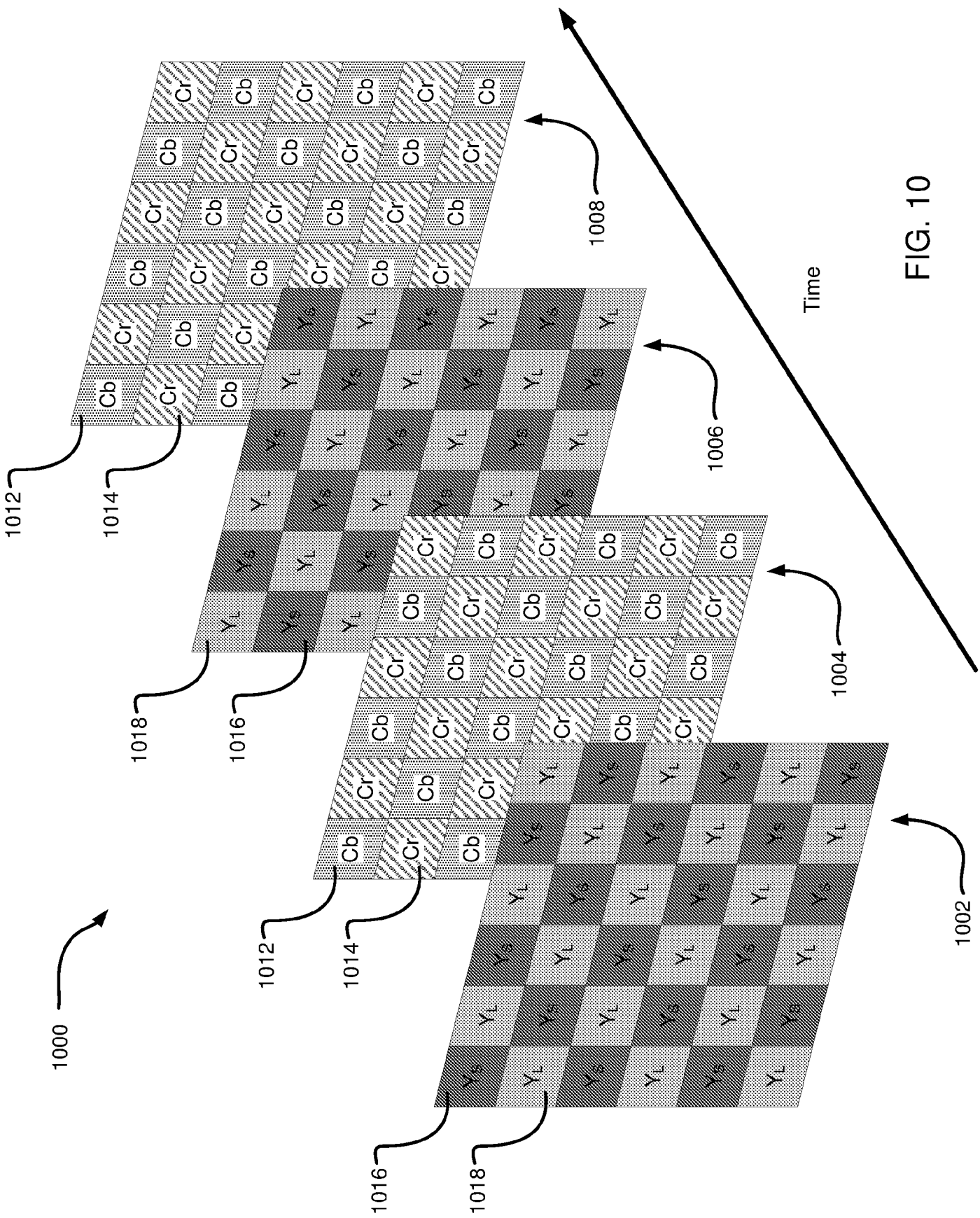


FIG. 10

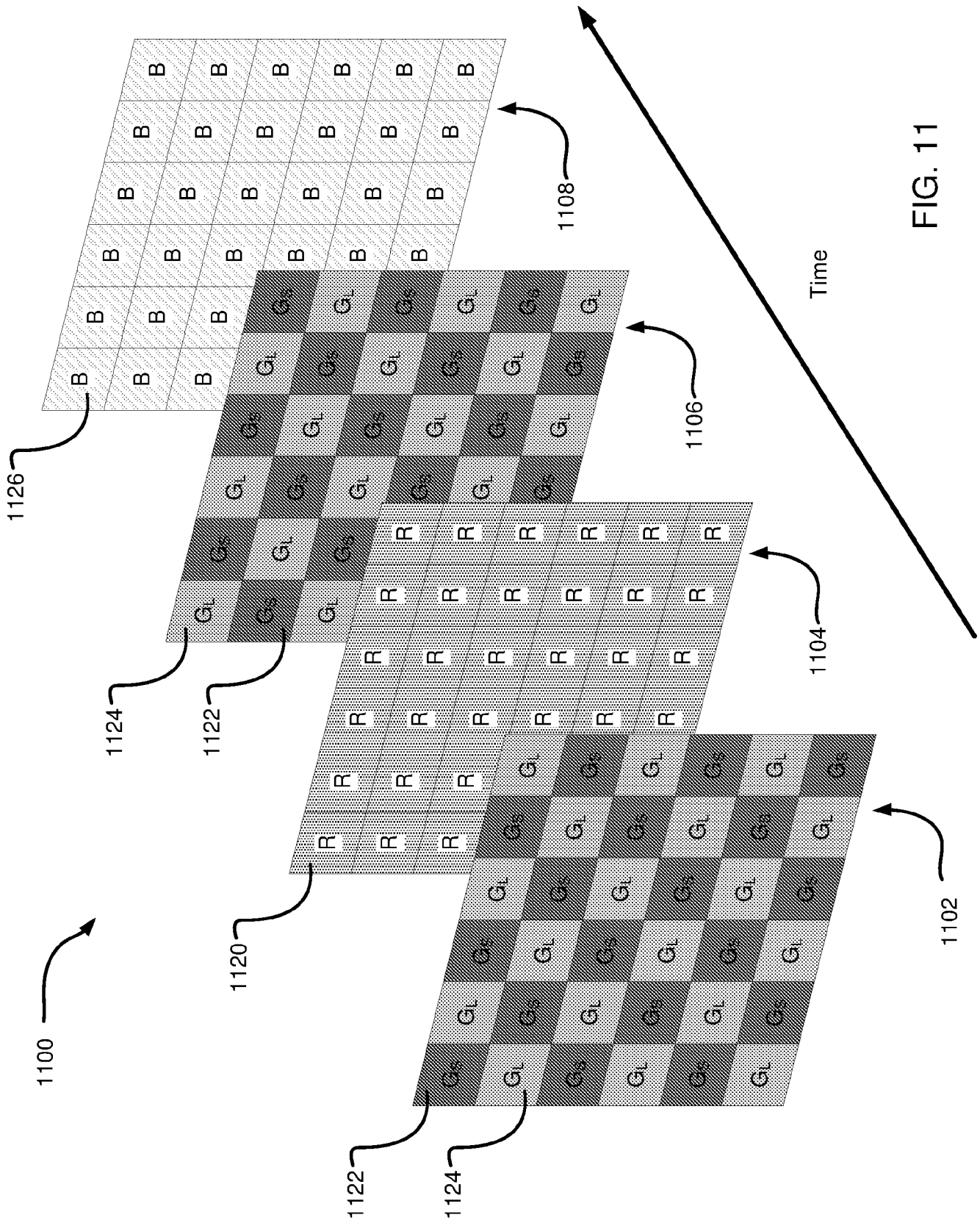


FIG. 11

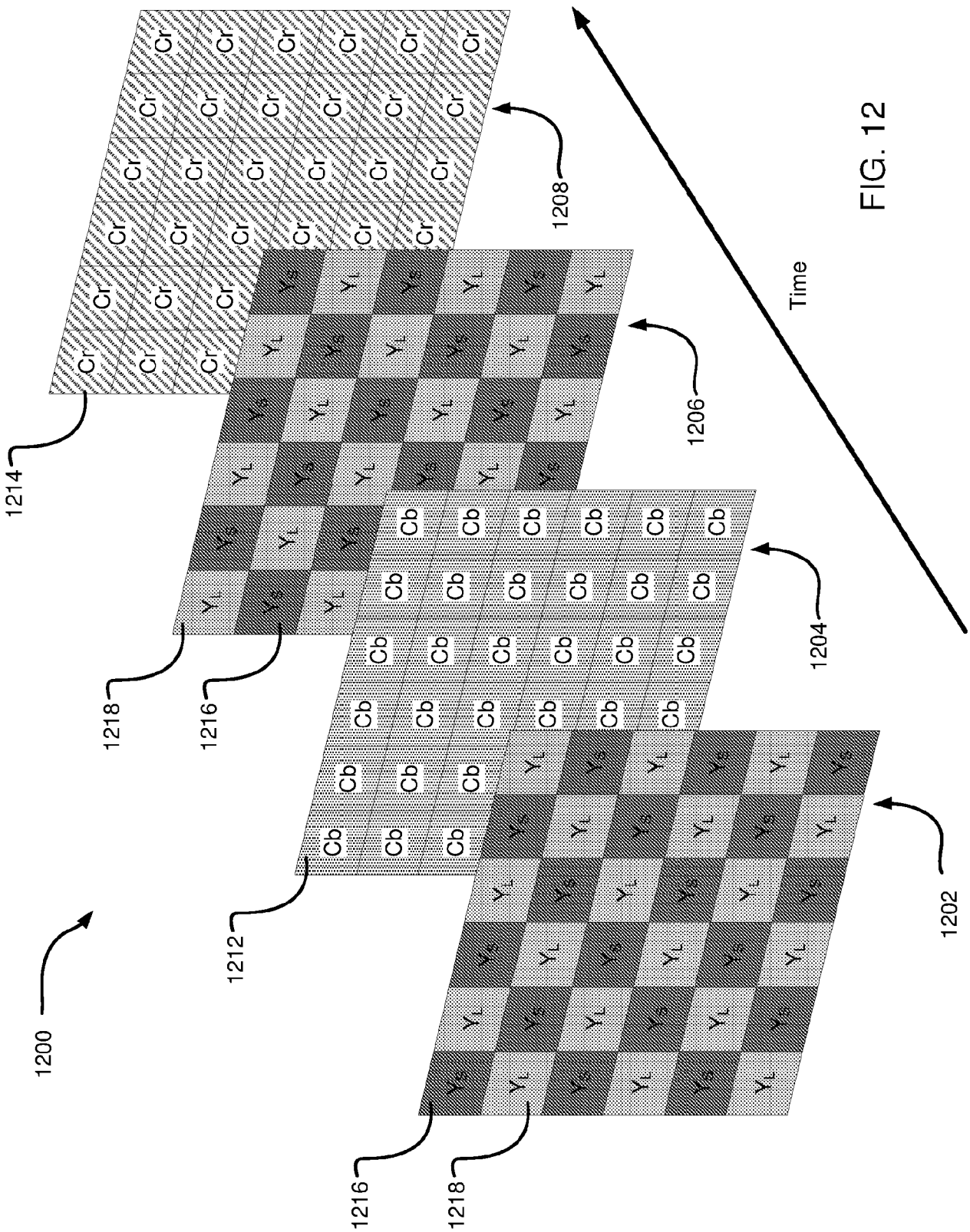


FIG. 12

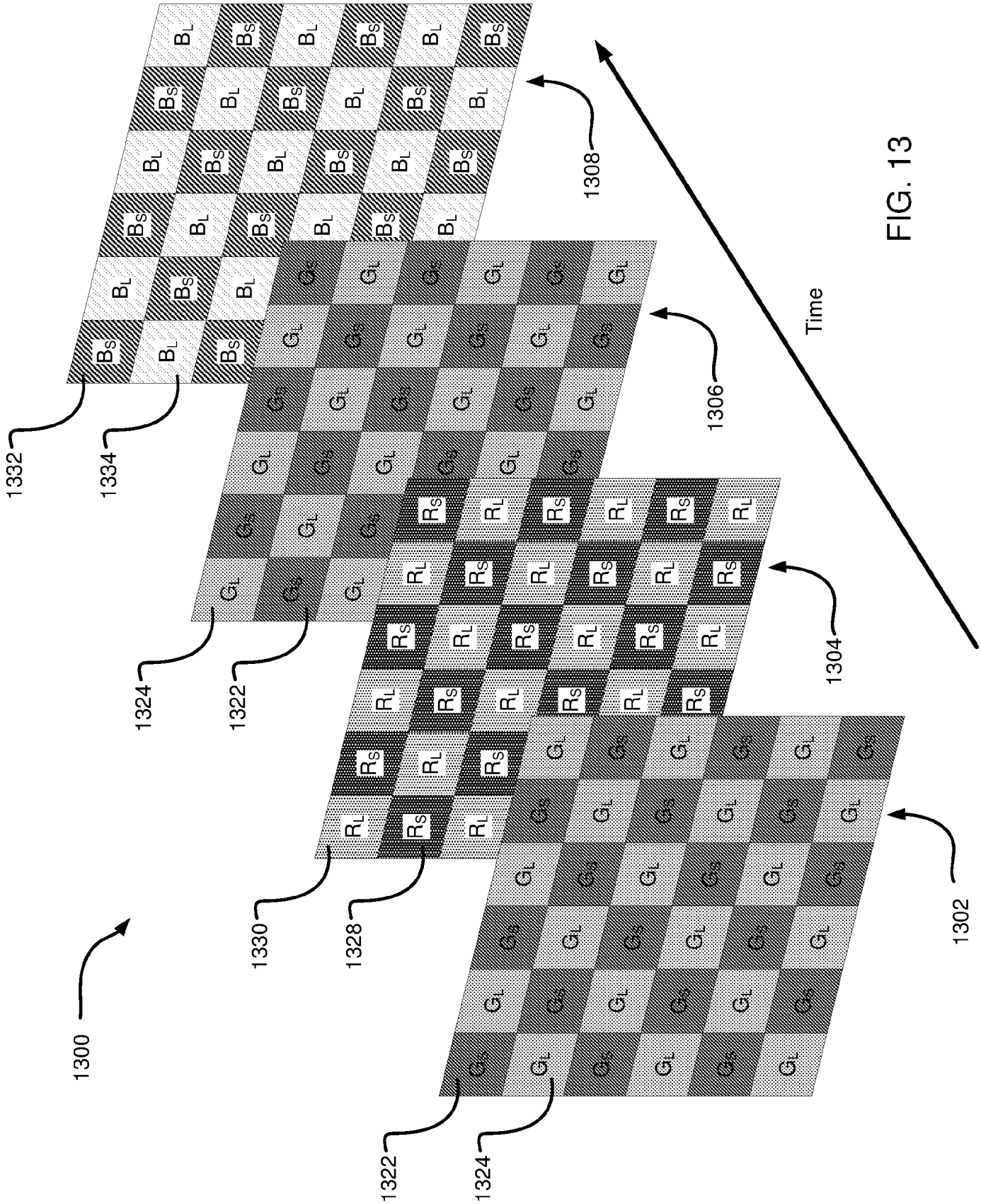


FIG. 13

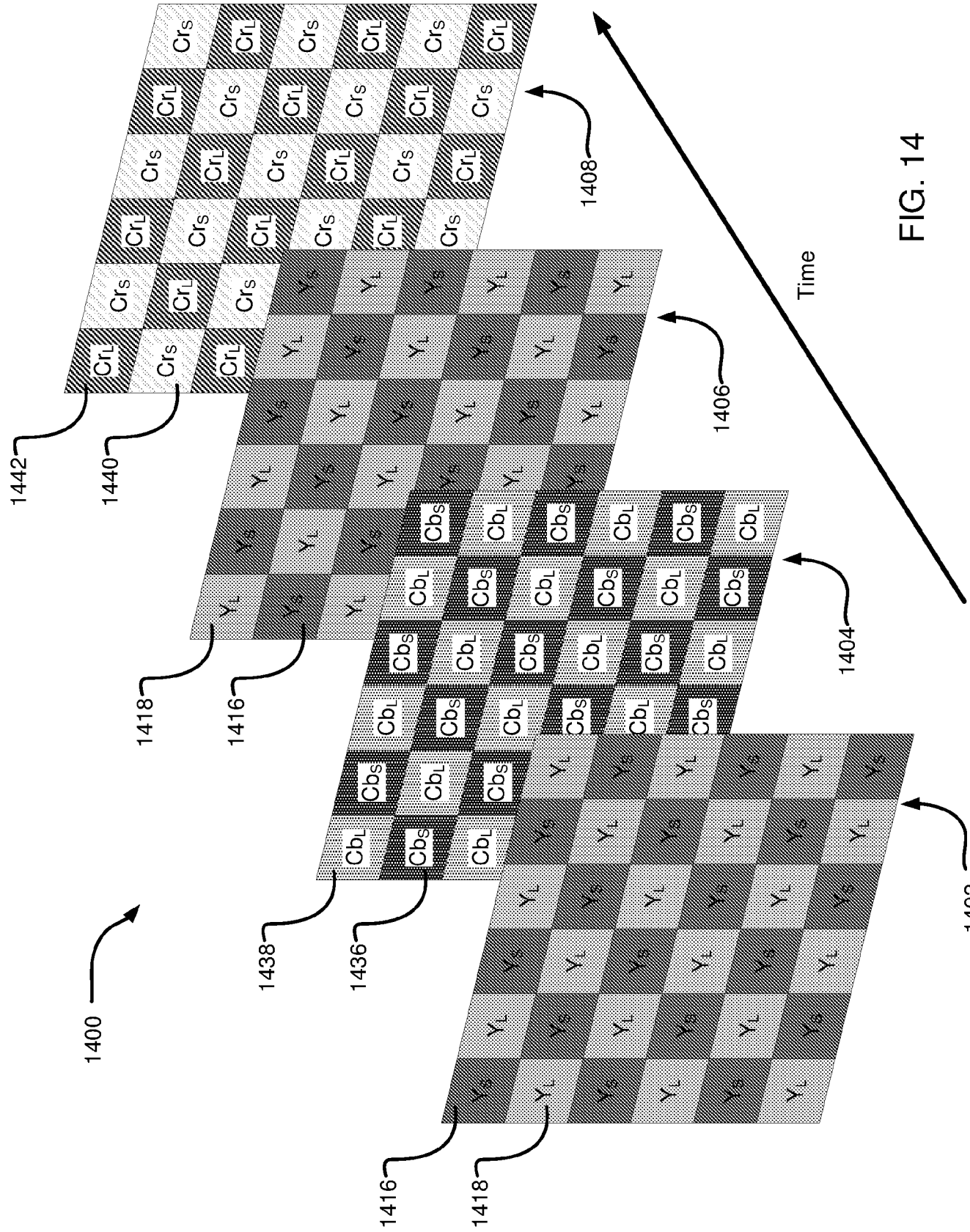


FIG. 14

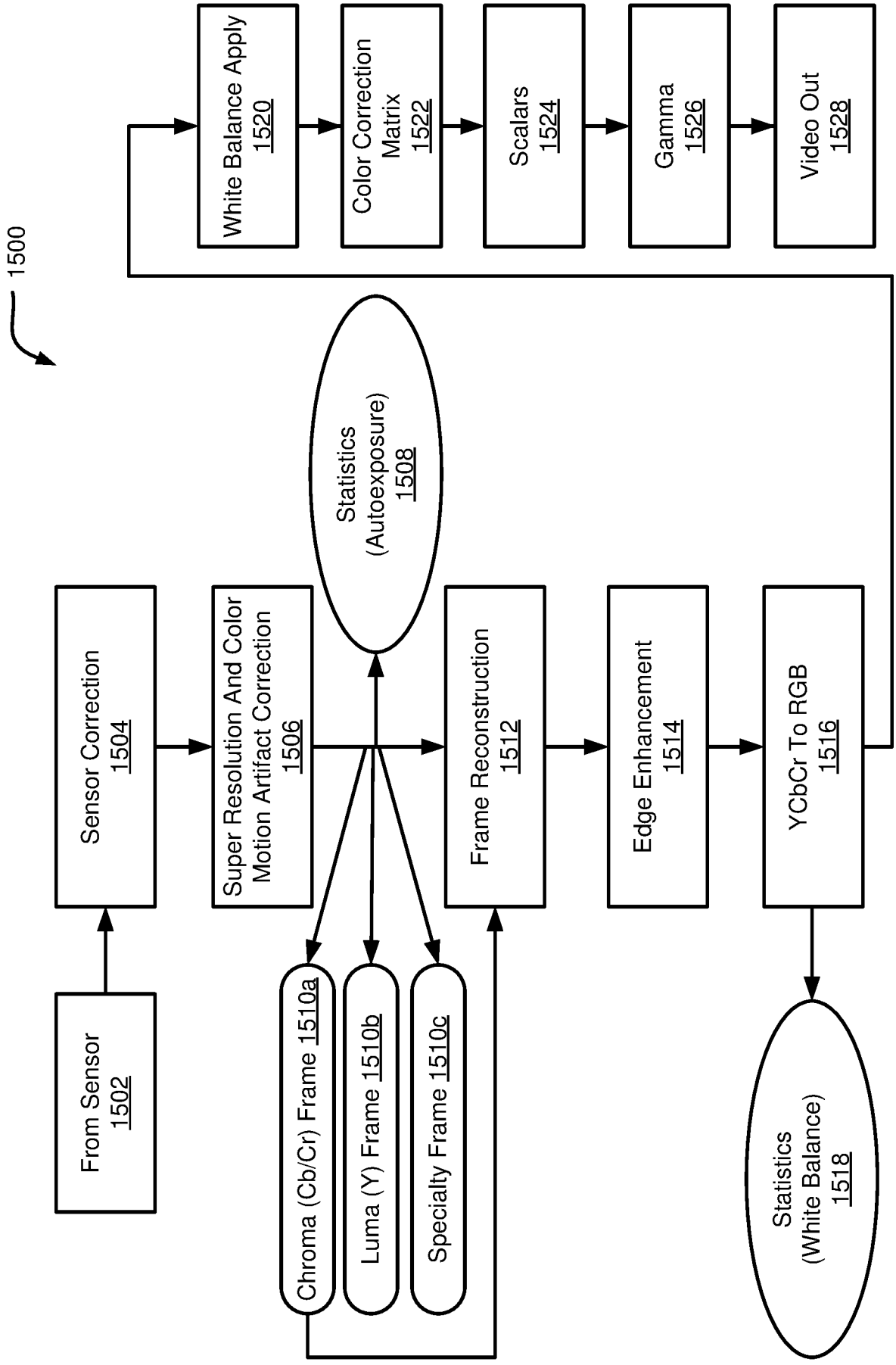

1500
From Sensor 1502
Sensor Correction 1504
Super Resolution And Color Motion Artifact Correction 1506
Statistics (Autoexposure) 1508
Chroma (Cb/Cr) Frame 1510a
Luma (Y) Frame 1510b
Specialty Frame 1510c
Frame Reconstruction 1512
Edge Enhancement 1514
YCbCr To RGB 1516
Statistics (White Balance) 1518
White Balance Apply 1520
Color Correction Matrix 1522
Scalars 1524
Gamma 1526
Video Out 1528

FIG. 15

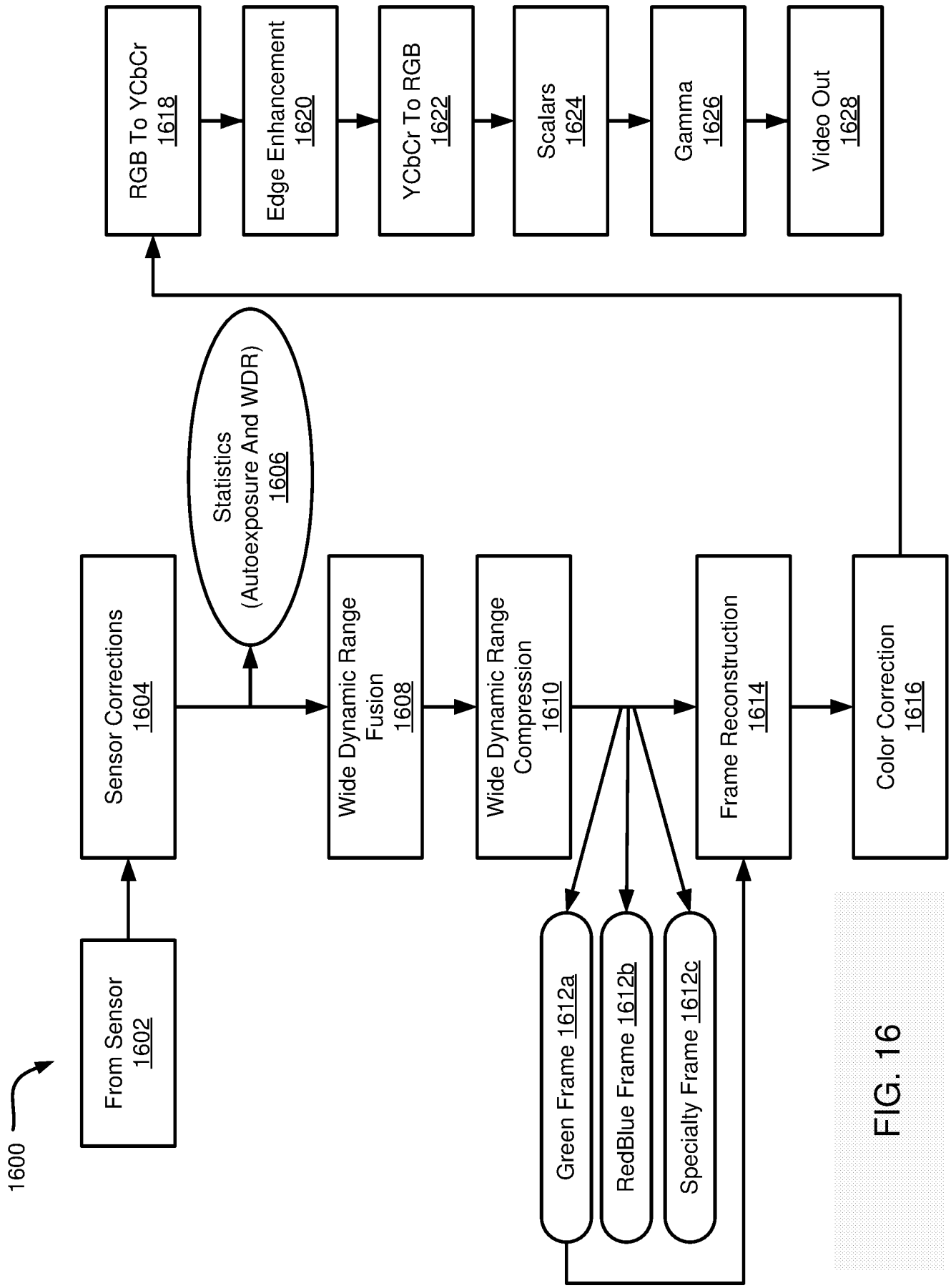

1600
From Sensor 1602
Sensor Corrections 1604
Statistics (Autoexposure And WDR) 1606
Wide Dynamic Range Fusion 1608
Wide Dynamic Range Compression 1610
Green Frame 1612a
RedBlue Frame 1612b
Specialty Frame 1612c
Frame Reconstruction 1614
Color Correction 1616
RGB To YCbCr 1618
Edge Enhancement 1620
YCbCr To RGB 1622
Scalars 1624
Gamma 1626
Video Out 1628

FIG. 16

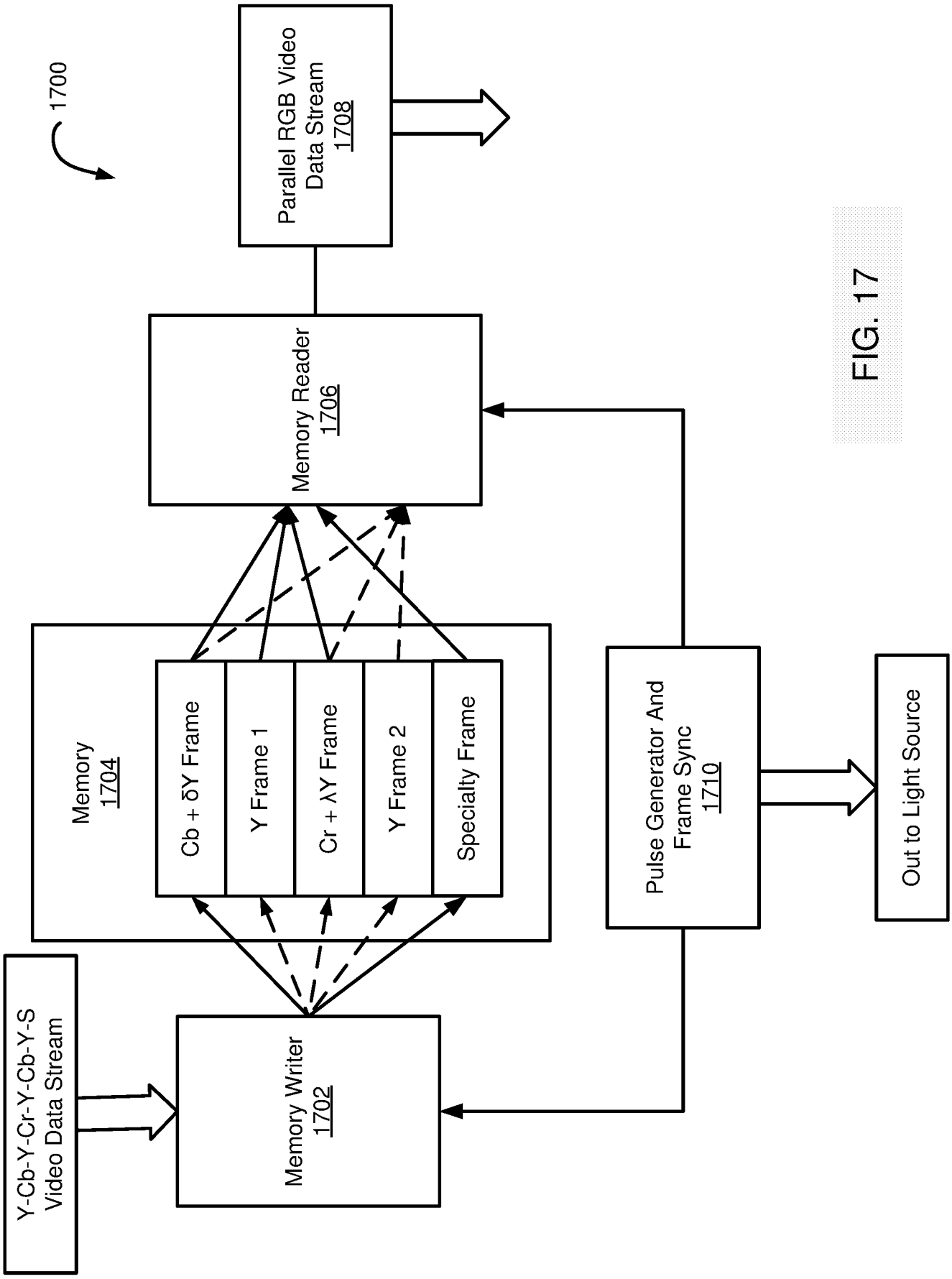

1700
Parallel RGB Video Data Stream 1708
Memory Reader 1706
Memory 1704
Cb + δY Frame
Y Frame 1
Cr + λY Frame
Y Frame 2
Specialty Frame
Pulse Generator And Frame Sync 1710
Out to Light Source
Memory Writer 1702
Y-Cb-Y-Cr-Y-Cb-Y-S Video Data Stream

FIG. 17

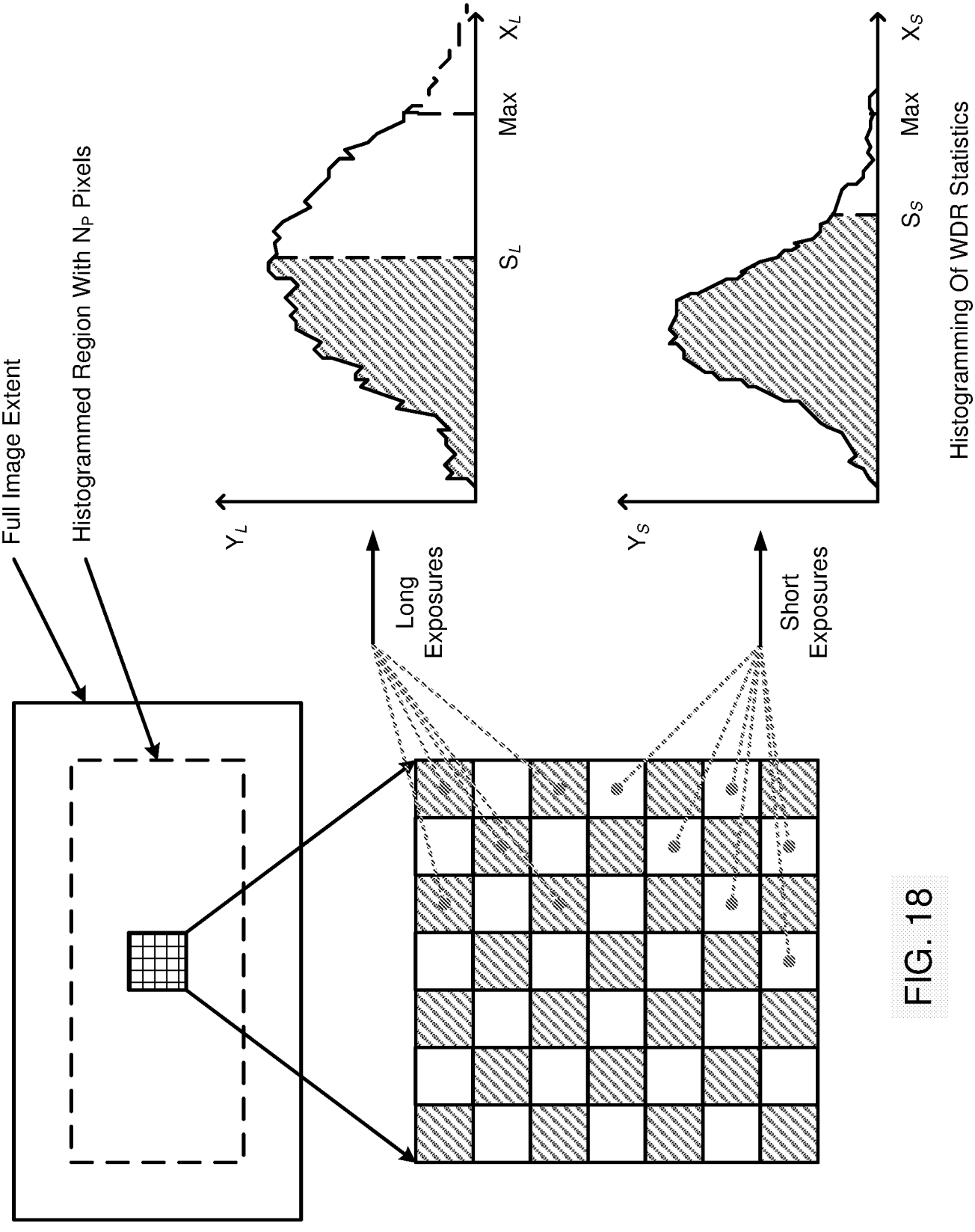

Full Image Extent
Histogrammed Region With N_P Pixels
Y_L
S_L
Max
X_L
Long Exposures
Y_S
S_S
Max
X_S
Short Exposures
Histogramming Of WDR Statistics

FIG. 18

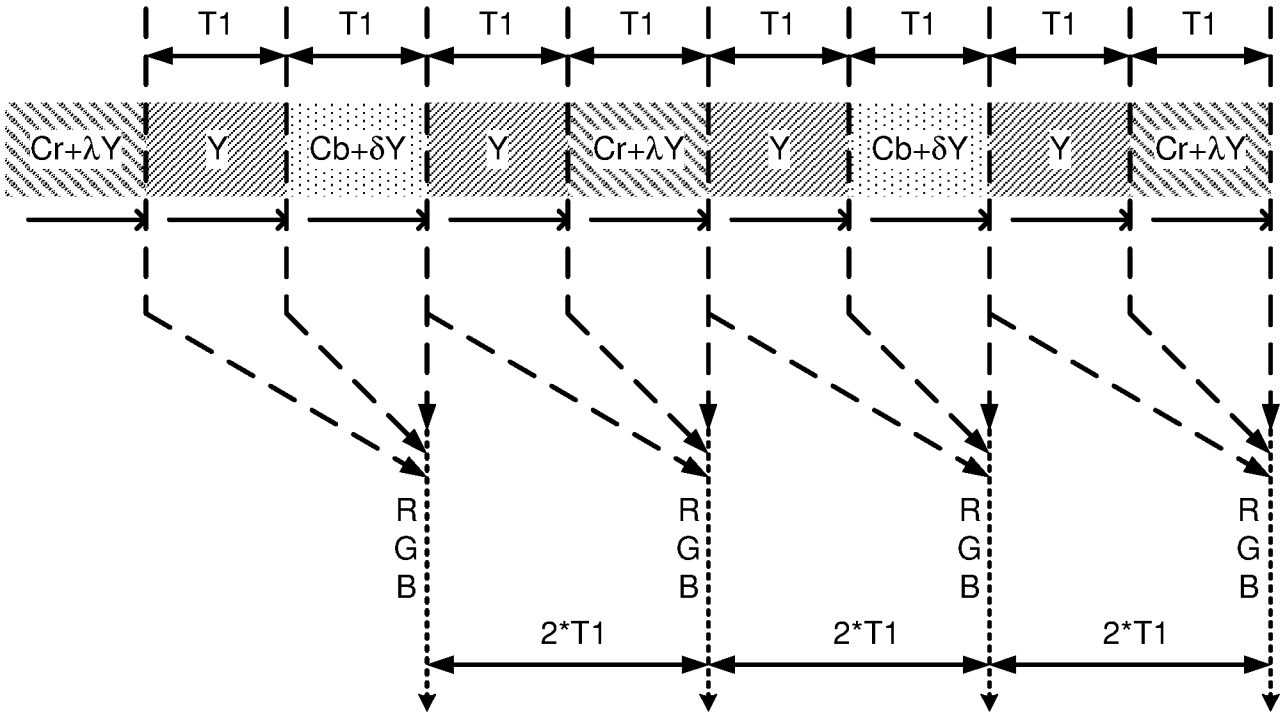


FIG. 19A

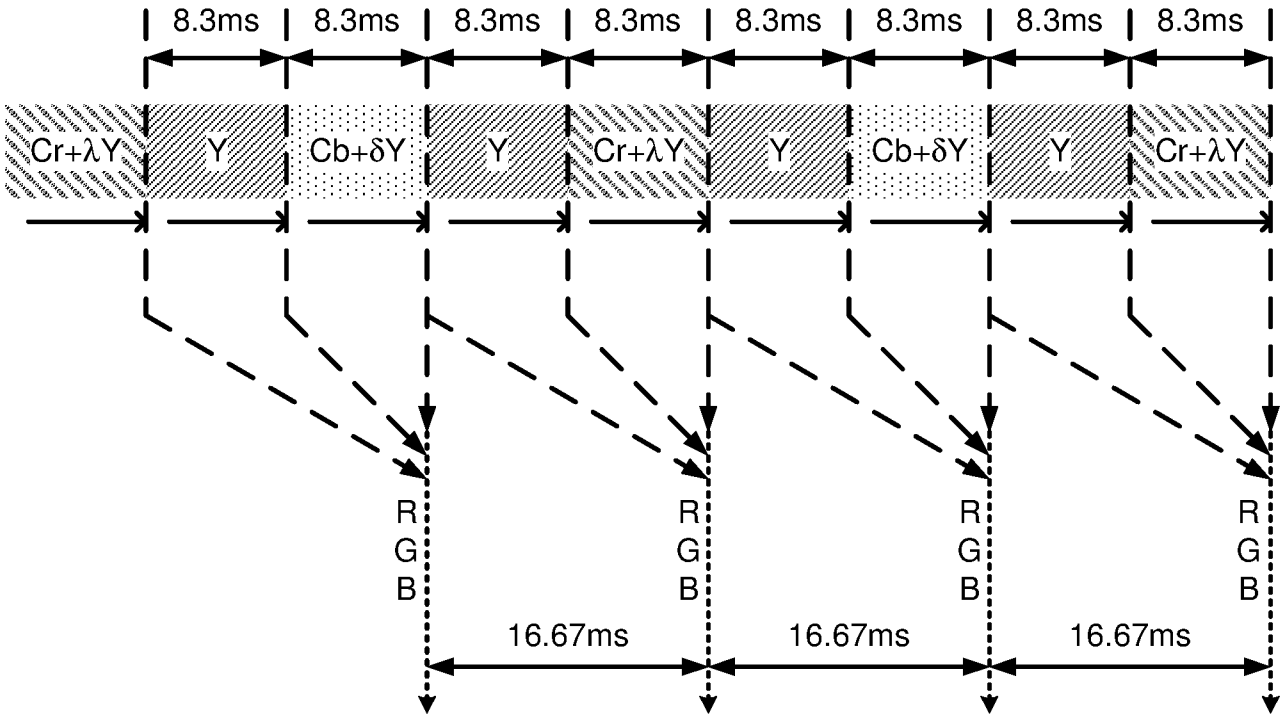


FIG. 19B

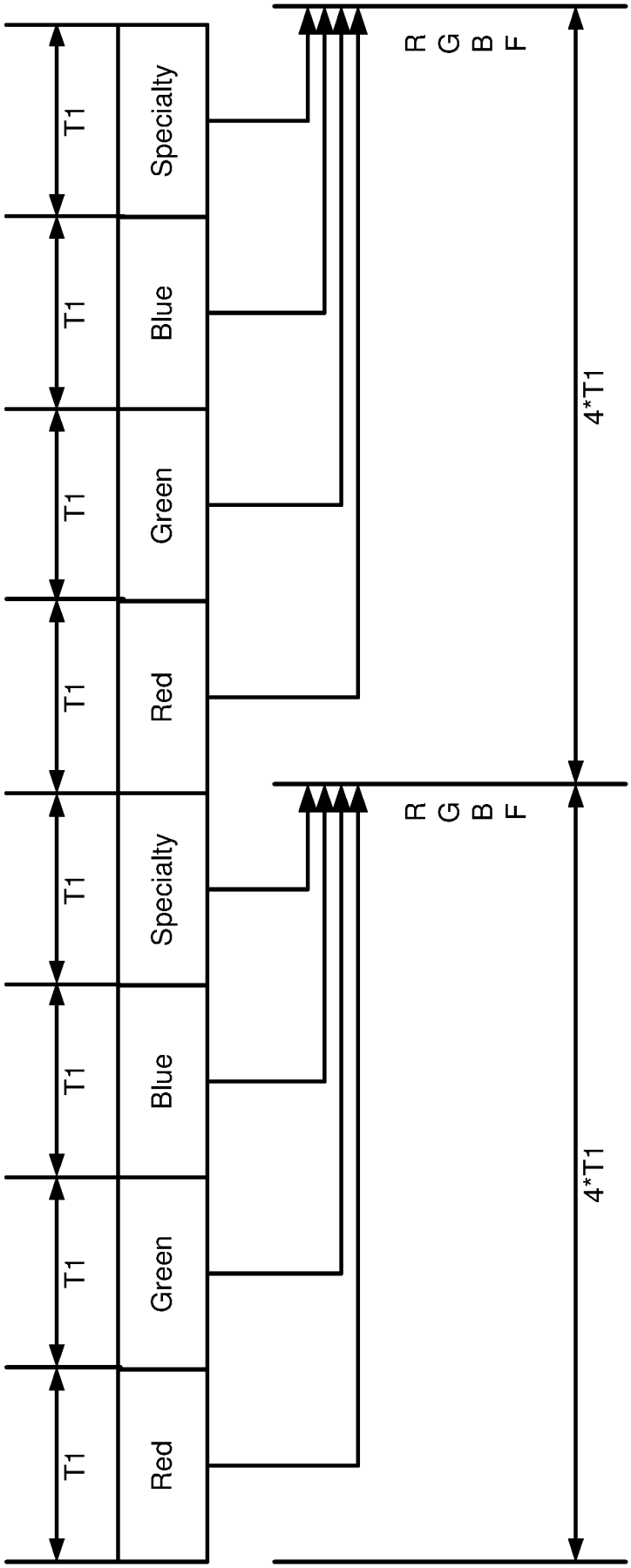

T1
Specialty
T1
Blue
T1
Green
T1
Red
T1
Specialty
T1
Blue
T1
Green
T1
Red
R
G
B
F
4*T1
R
G
B
F
4*T1

FIG. 20

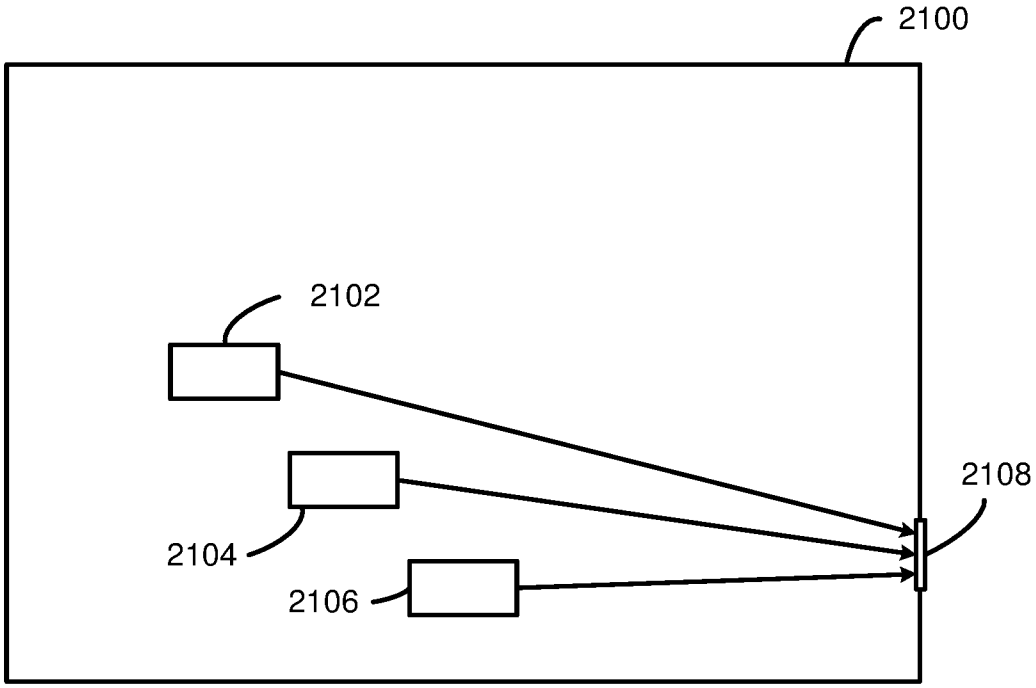


FIG. 21A

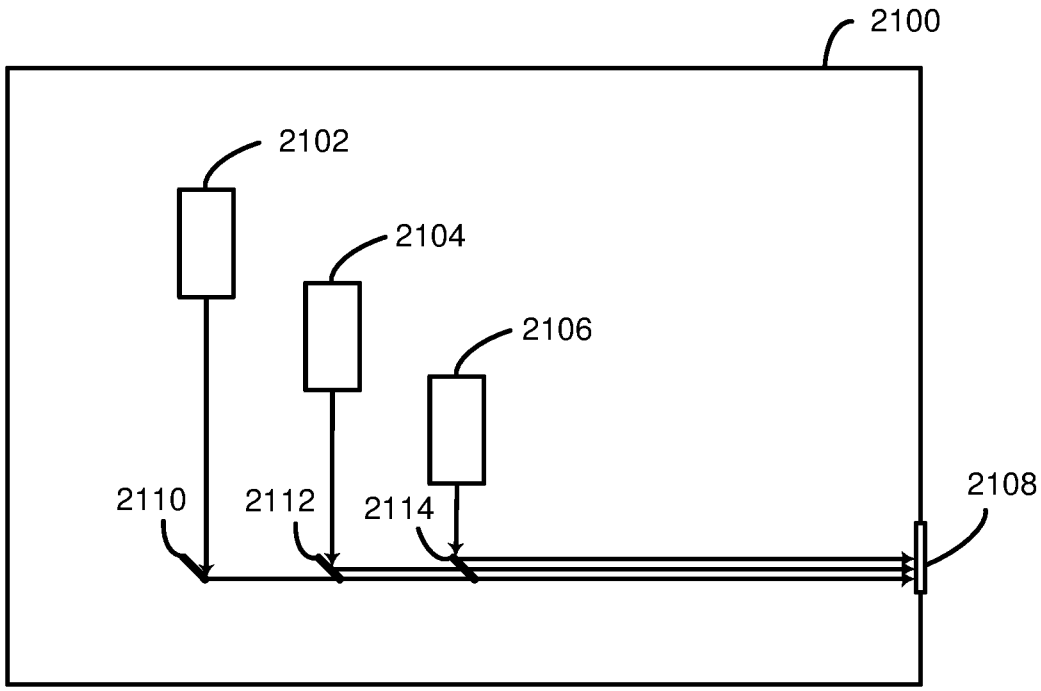


FIG. 21B

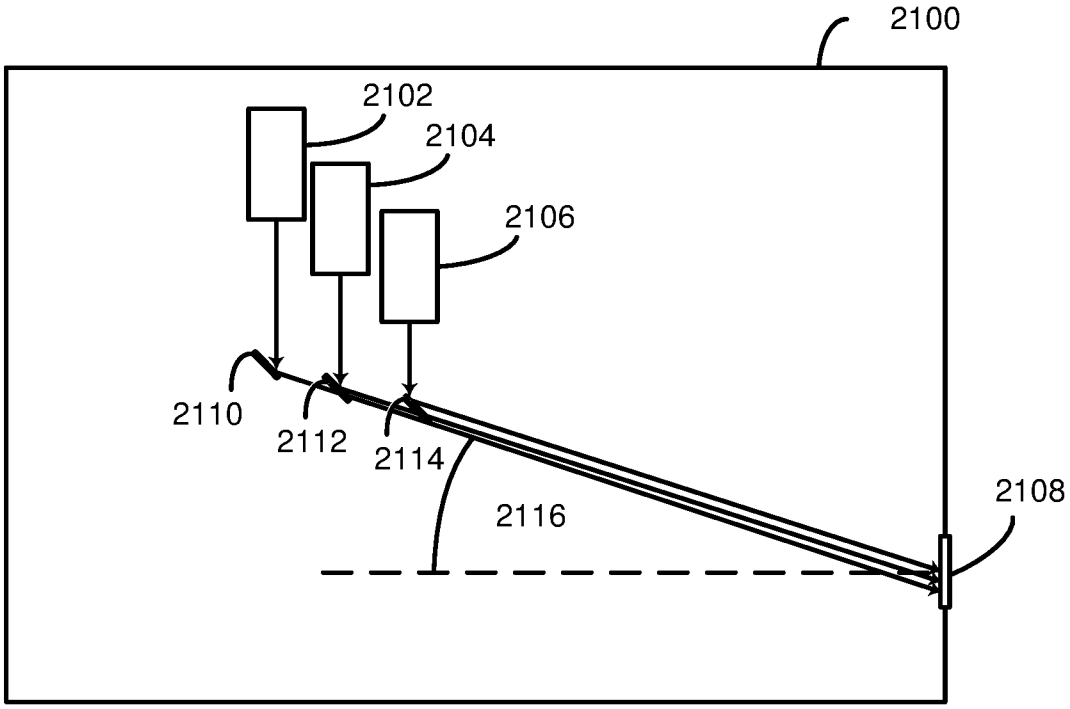


FIG. 21C

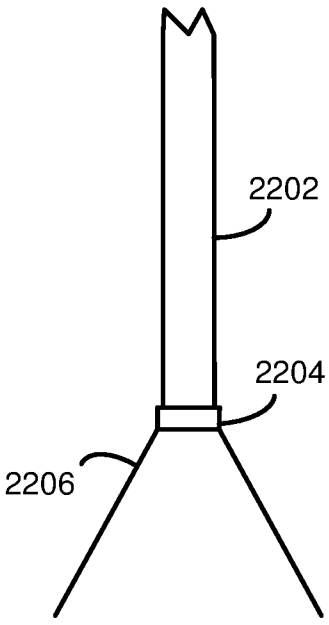


FIG. 22

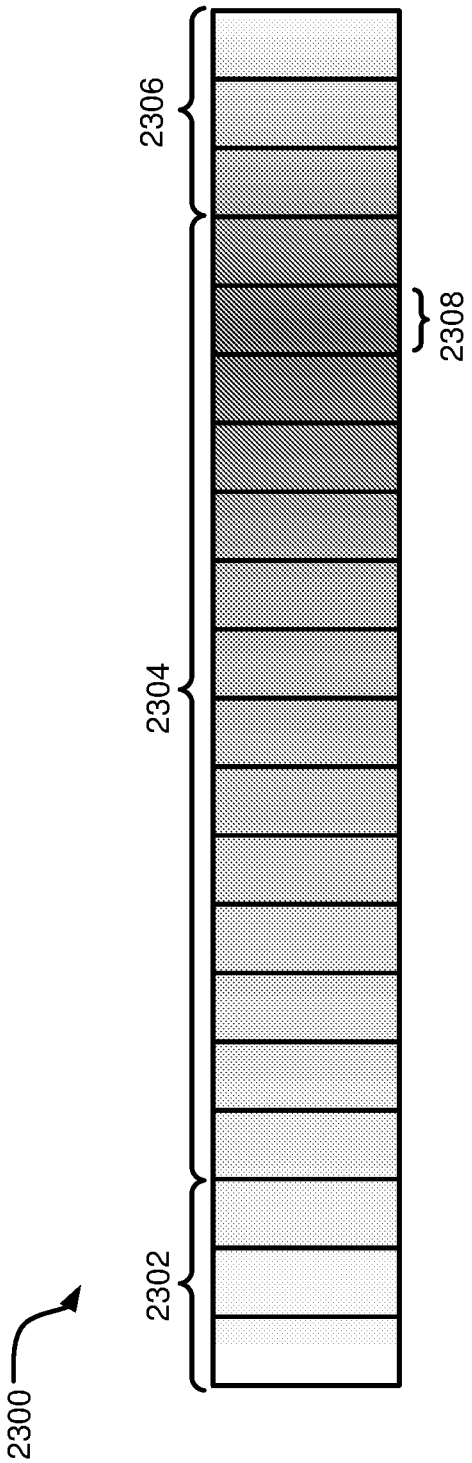

2300
2302
2304
2306
2308

FIG. 23

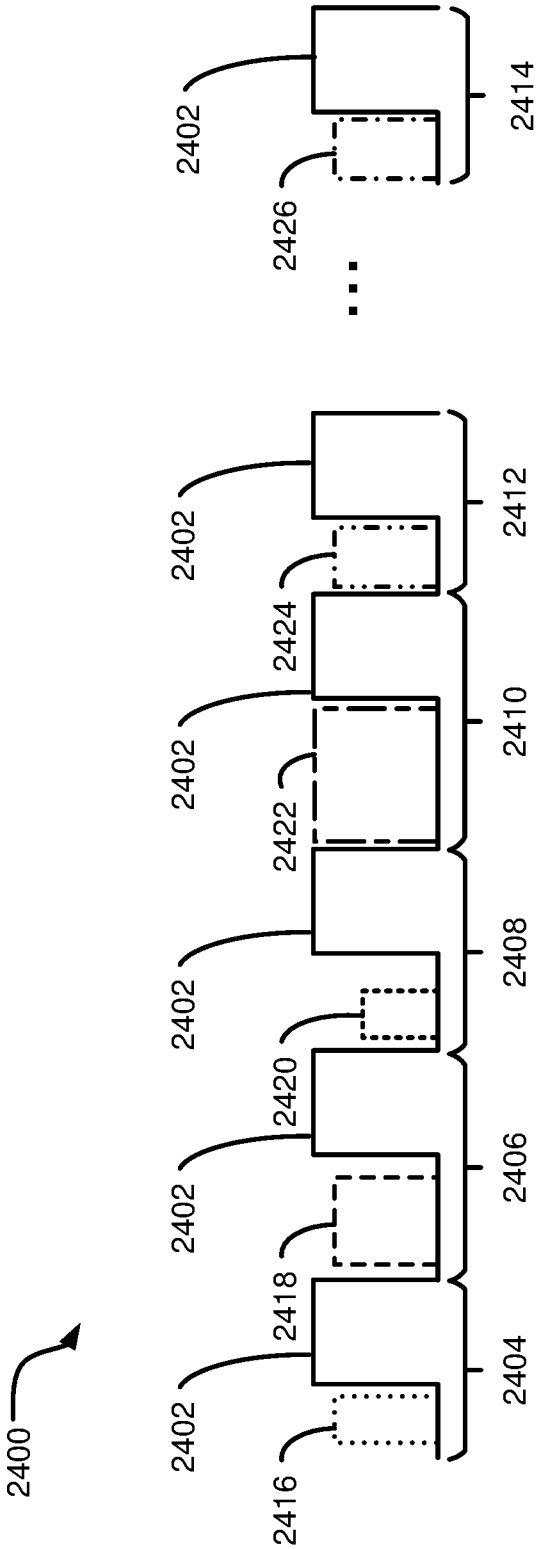

2400
2402
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2426

FIG. 24

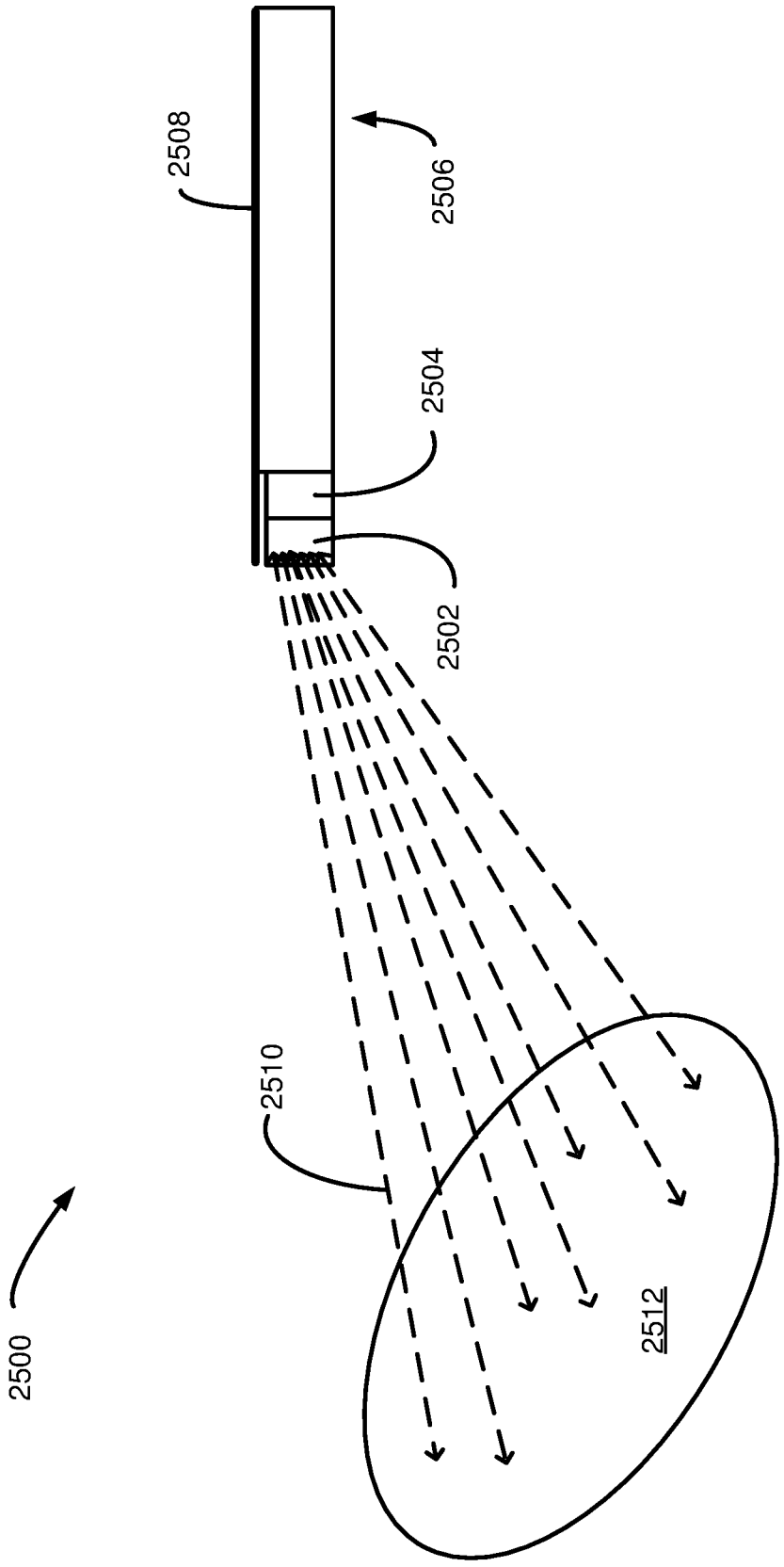


FIG. 25

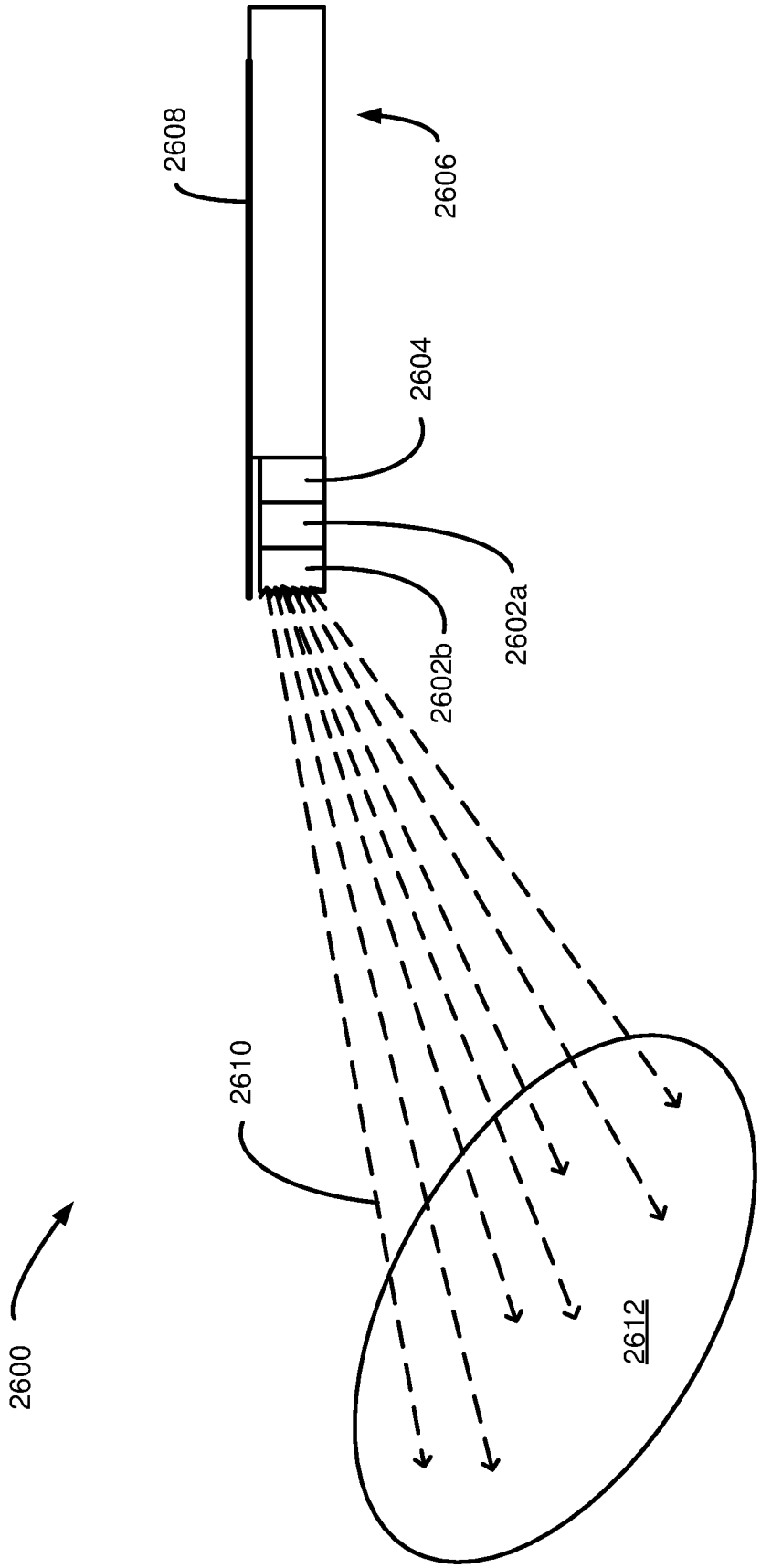


FIG. 26

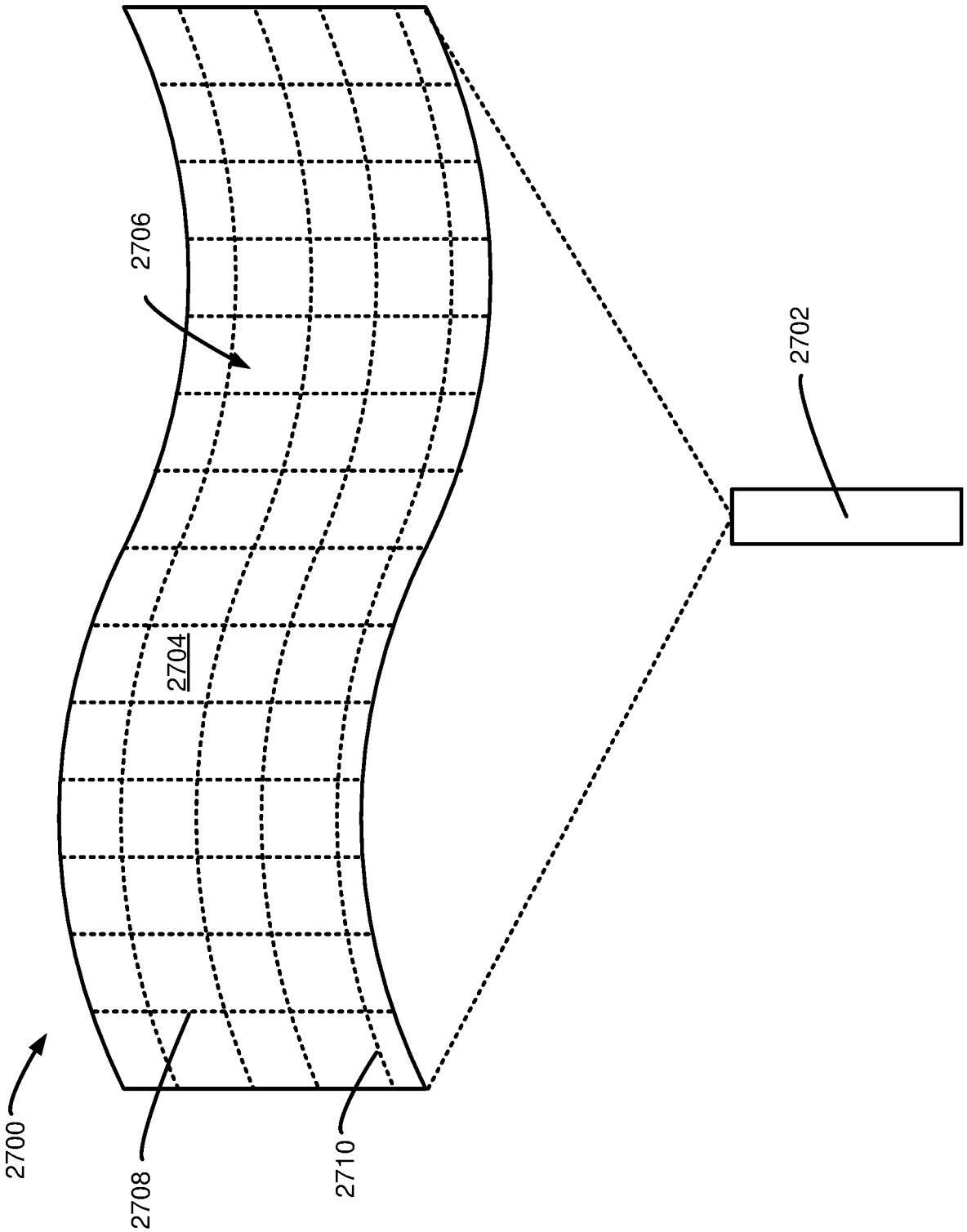


FIG. 27

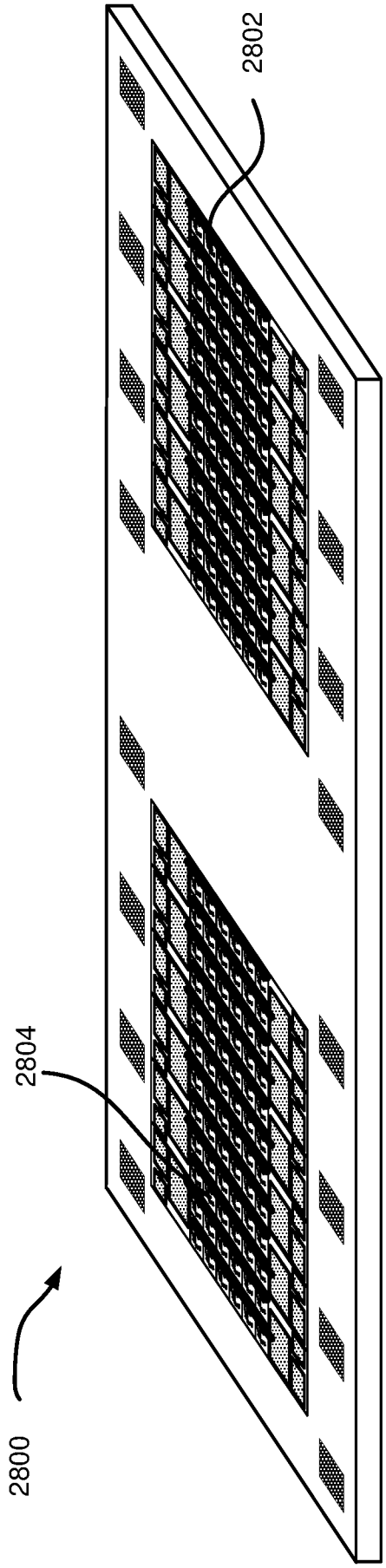


FIG. 28A

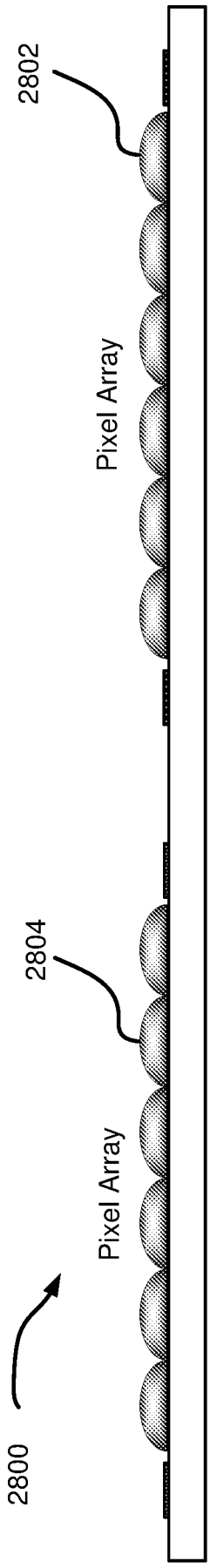


FIG. 28B

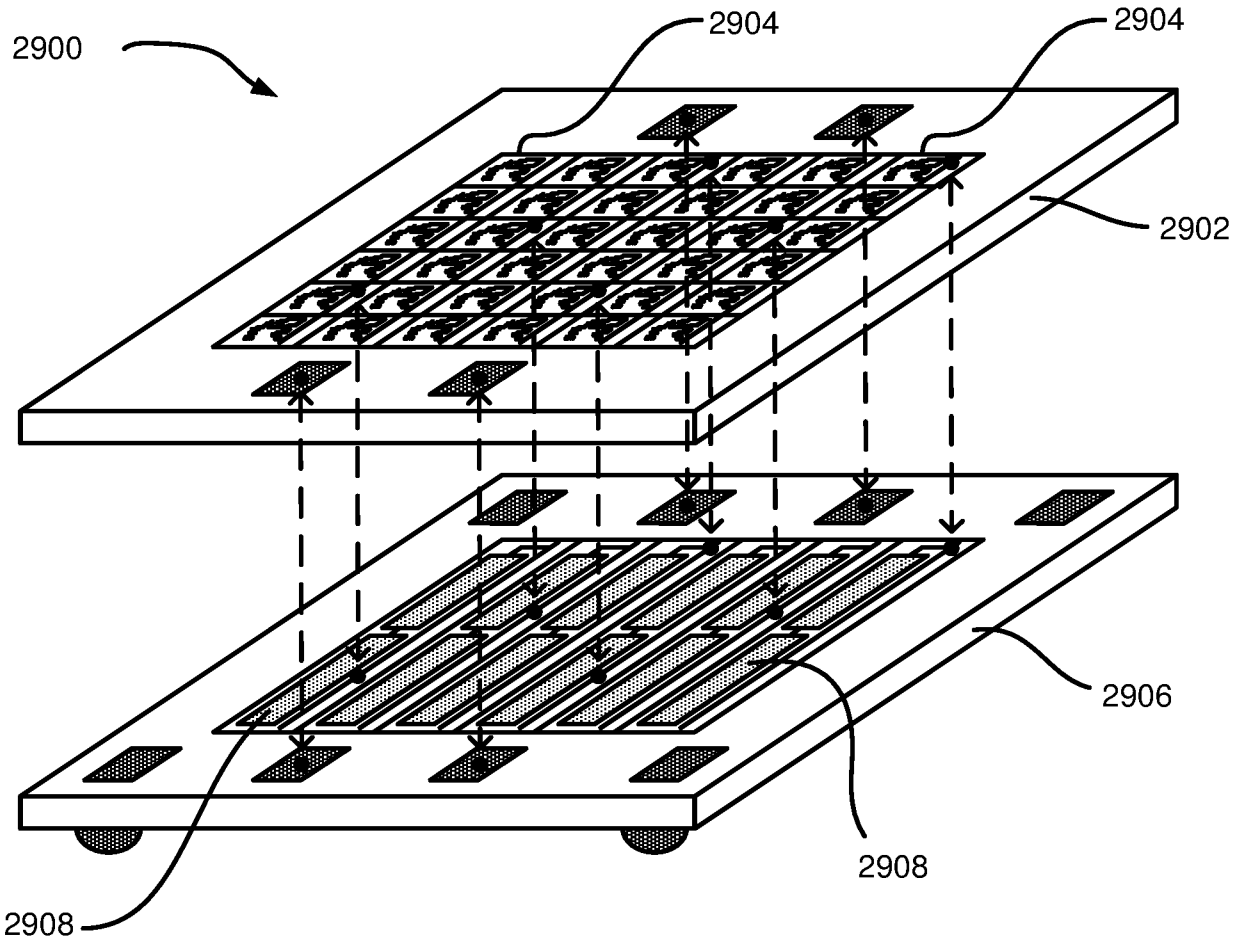


FIG. 29A

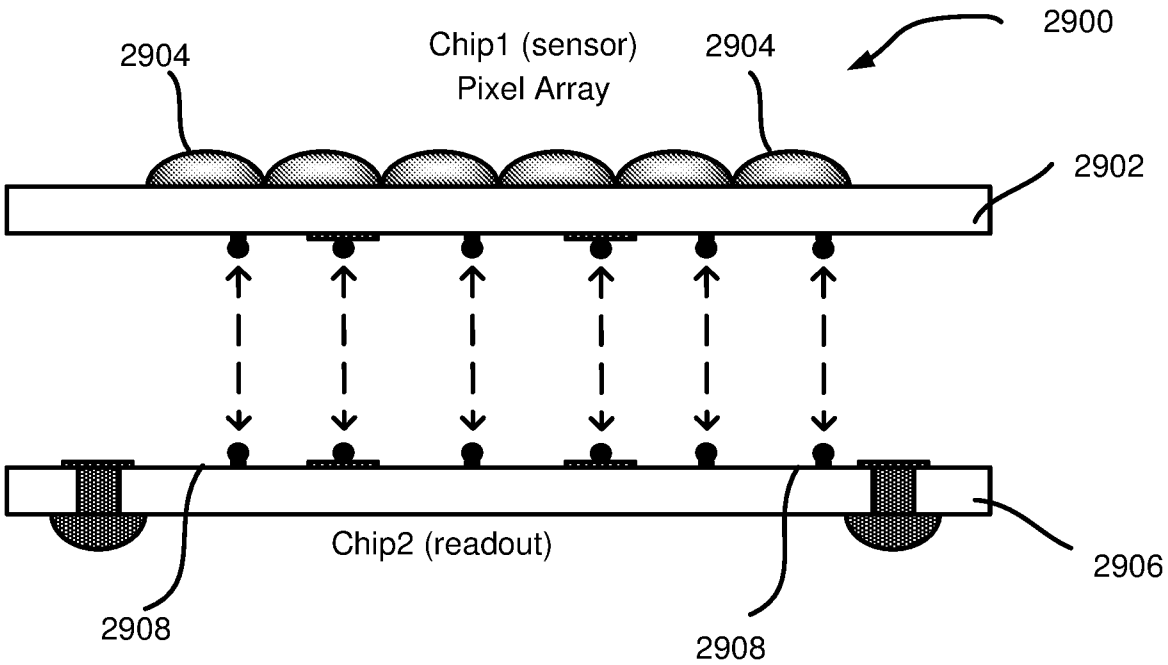


FIG. 29B

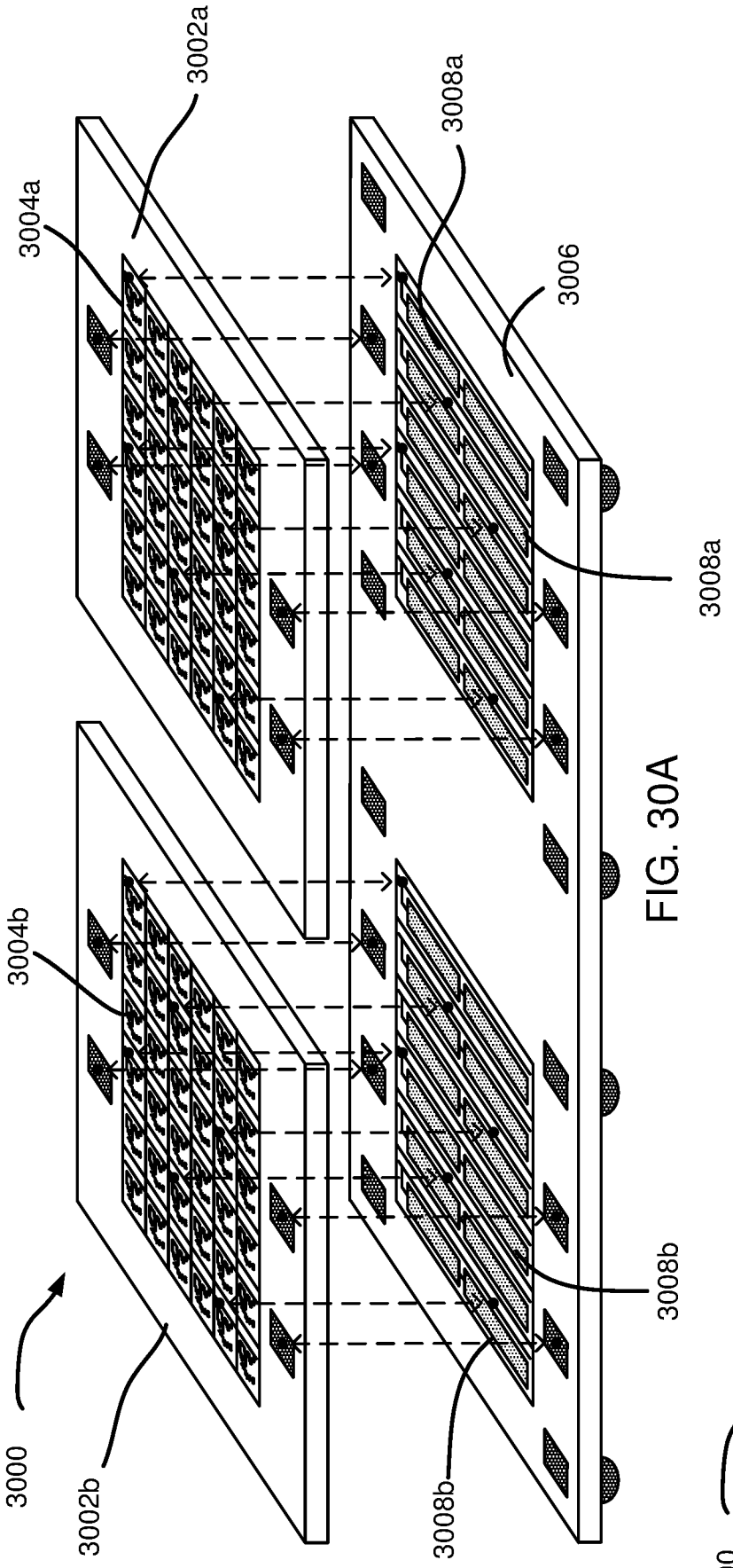


FIG. 30A

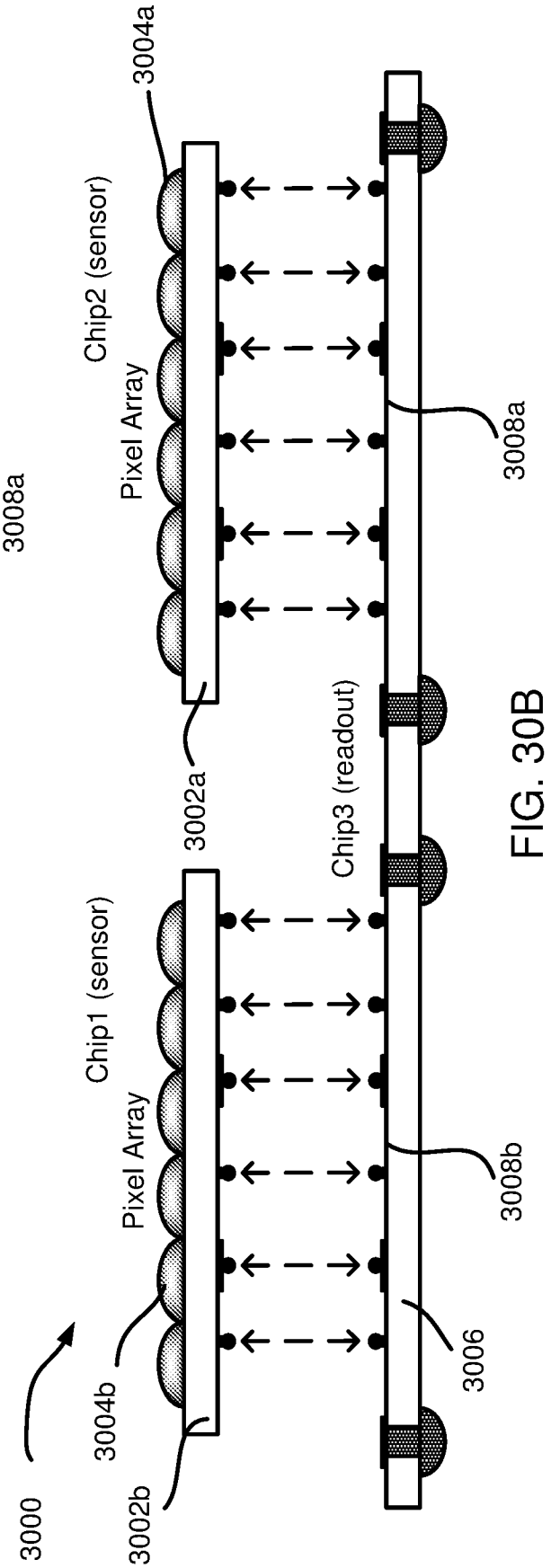


FIG. 30B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/37068

A. CLASSIFICATION OF SUBJECT MATTER
IPC - A61B 1/00; A61B 1/05 (2020.01)
CPC - A61B 1/05; A61B 1/06; A61B 1/063

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)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2018/0014000 A1 (DePuy Synthes Products, Inc.) 11 January 2018 (11.01.2018); entire document, especially, abstract, FIG.3c, 4, 13, 16A, para [0009], [0035], [0036], [0038], [0041]-[0043], [0049], [0051], [0064], [0065], [0073], [0075], [0078], claim 32, 36, 37, 40, 45, 46 and 52.	1, 3-5, 9, 10, 14, 25-27 ---------- 2, 6-8, 11-13, 15-24, 28-30
Y	US 2015/0116539 A1 (The Trustees of Columbia University in the City of New York et al.) 30 April 2015 (30.04.2015); entire document, especially, abstract, FIG.4A, 4B, para [0013], [0060], [0061]	2
Y	US 2008/0226029 A1 (Weir et al.) 18 September 2008 (18.09.2008); entire document, especially, abstract, FIG.1, 2, para [0022], [0023], [0026], [0028], [0046], [0063], [0071], [0073], [0074], [0076],[0091], [0092]	6-8, 11, 15-19, 23, 24, 29
Y	US 2008/0240502 A1 (Freedman et al.) 02 October 2008 (02.10.2008); entire document, especially, abstract, FIG.2, para [0006], [0046], [0047], [0052], [0058]	12
Y	US 2003/0060683 A1 (Abe et al.) 27 March 2003 (27.03.2003); entire document, especially, abstract, FIG.1, para [0021], [0024]	13
Y	US 2003/0191368 A1 (Wang et al.) 09 October 2003 (09.10.2003); entire document , especially, abstract, para [0031], [0057], [0059], [0060], [0065],	17-24, 28
Y	US 2013/0274596 A1 (Children's National Medical Center) 17 October 2013 (17.10.2013); entire document, especially, abstract, FIG.10, para [0020], [0070], [0092]	30

☐ 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
"D" document cited by the applicant in the international application
"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
15 August 2020	11 SEP 2020
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300