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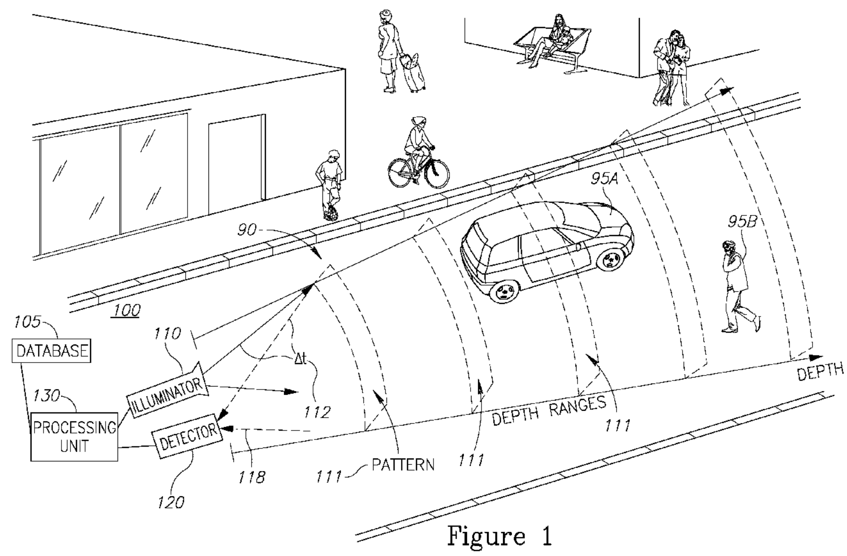

Figure 1

(57) Abstract: Methods and systems are provided, which illuminate a scene with pulsed patterned light having one or more spatial patterns; detect reflections of the pulsed patterned light from one or more depth ranges in the scene, by activating a detector for detecting the reflections only after respective traveling times of the illumination pulses, which correspond to the depth ranges, have elapsed; and derive an image of the scene from the detected reflections and according to the spatial patterns. The methods and systems integrate gated imaging and structured light synergistically to provide required images which are differentiated with respect to object ranges in the scene and different patterns applied with respect to the objects and their ranges.

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GATED STRUCTURED IMAGING

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

[0001] The present invention relates to the field of imaging, and more particularly, to combining gated imaging and structured light methods synergistically and to providing a range map from objects.

2. DISCUSSION OF RELATED ART

[0002] WIPO Publication No. 2015/004213, which is incorporated herein by reference in its entirety, discloses a system for detecting the profile of an object, which comprises a radiation source for generating a radiation pattern, a detector which has a plurality of pixels and a processor for processing data from the detector when radiation from the radiation source is reflected by an object and detected by the detector. The system also comprises a synchronization means interfacing between the detector and the radiation source. The radiation source is designed for operating in pulsed mode and the synchronization means can synchronize the pulses of the radiation source with the sampling of the detector.

[0003] U.S. Patent Publication No. 20130222551, which is incorporated herein by reference in its entirety, discloses a method for video capturing that illuminates a stationary outdoor scene containing objects, with a structured light exhibiting a specified pattern, at a first angle; captures reflections from the objects in the stationary scene, in a second angle, the reflections exhibiting distortions of the specified pattern; and analyzes the reflected distortions of the specified pattern, to yield a three dimensional model of the stationary scene containing the objects, wherein the specified pattern may include temporal and spatial modulation.

[0004] U.S. Patent No. 8,194,126, which is incorporated herein by reference in its entirety, discloses a method of gated imaging. Light source pulse (in free space) is defined as: $T_{LASER} = 2(\frac{R_0 - R_{MIN}}{c})$, wherein the parameters are defined below. Gated camera ON time (in free space) is defined as: $T_{II} = 2(\frac{R_{MAX} - R_{MIN}}{c})$. Gated camera OFF time (in free space) is defined as: $T_{OFF} = 2\frac{R_{MIN}}{c}$, where c is the speed of light, R_0, R_{MIN} and R_{MAX} are specific ranges. The gated imaging is utilized to create a sensitivity as a function of range through time synchronization of T_{LASER}, T_{II} and T_{OFF}.

[0005] Hereinafter a single "Gate" (i.e., at least a single light source pulse illumination followed by at least a single camera/sensor exposure per a single readout) utilizes a specific T_{LASER}, T_{II} and T_{OFF} timing as defined above. Hereinafter "Gating"/"Gating parameters" (i.e. at least a single sequences of; a single light source pulse illumination followed by a single camera/sensor exposure and a single light source pulse illumination followed by a single camera/sensor exposure ending the sequence a single image readout) utilizes each sequence a specific T_{LASER}, T_{II} and T_{OFF} timing as defined above.

SUMMARY OF THE INVENTION

[0006] The following is a simplified summary providing an initial understanding of the invention. The summary does not necessarily identify key elements nor limit the scope of the invention, but merely serves as an introduction to the following description.

[0007] One aspect of the present invention provides a method comprising: (i) illuminating a scene with pulsed patterned light having at least one specified spatial pattern, (ii) detecting reflections of the pulsed patterned light from at least one specified range in the scene, by activating a detector for detecting the reflections only after at least one traveling time of the respective illumination pulse, corresponding to the at least one specified range, has elapsed, and (iii) deriving an image of at least a part of the scene within the at least one specified range, from the detected reflections and according to the at least one spatial pattern.

[0008] These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed description which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a better understanding of embodiments of the invention and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections throughout.

[0010] In the accompanying drawings:

[0011] **Figure 1** is a high level schematic block diagram of a system for imaging a scene, according to some embodiments of the invention.

[0012] Figure 2A is a high level flowchart illustrating optional uses of the system, according to some embodiments of the invention**.**

[0013] Figure 2B is a high level schematic block diagram illustrating synergistic effects of structured light and gated imaging employed by the system, according to some embodiments of the invention.

[0014] Figure 3A is a high level schematic illustration of a part of the illuminator, according to some embodiments of the invention.

[0015] Figure 3B schematically illustrates pattern changes at different depth ranges, according to some embodiments of the invention.

[0016] Figures 4A and **4B** schematically illustrate pattern adaptations, according to some embodiments of the invention.

[0017] Figures 5A-5H schematically illustrate various patterns, according to some embodiments of the invention.

[0018] Figure 6 is an exemplary illustration of images derived by the system, according to some embodiments of the invention.

[0019] Figures 7A and **7B** are high level schematic illustrations of the scene with applied adaptive virtual fences, according to some embodiments of the invention.

[0020] Figures 8A and **8B** are high level schematic illustrations of the detector, according to some embodiments of the invention.

[0021] Figures 9A and **9B** schematically illustrate related temporal sequences of illumination and detection parameters, according to some embodiments of the invention.

[0022] Figures 10A-10D schematically illustrate handling the pixel array of the detector, according to some embodiments of the invention.

[0023] Figure 11 is a high level flowchart illustrating a method, according to some embodiments of the invention.

[0024] Figures 12A-12D are high level schematic block diagrams of systems configurations, according to some embodiments of the invention.

[0025] Figures 13A and **13B** are high level schematic illustrations of measuring vehicle distances, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] Prior to the detailed description being set forth, it may be helpful to set forth definitions of certain terms that will be used hereinafter.

[0027] The terms "structured light" or "patterned illumination" as used in this application refer to the use of projected spatial designs of radiation on a scene and geometrically deriving from reflections thereof three dimensional (3D) characteristics of the scene. It is noted that illumination may be in infrared (any of different wavelength ranges) and/or in the visible range.

[0028] The terms "depth" or "depth range" as used in this application refer to distances between scene segments and illuminators and/or detectors. The terms "depth" or "depth range" may relate to a single distance, a range of distances and/or weighted distances or distance ranges in case illuminator(s) and detector(s) are spatially separated. The term "traveling time" as used in this application refers to the time it takes an illumination pulse to travel from an illumination source to a certain distance (depth, or depth range) and back to the detector (see more details below).

[0029] The term "gated imaging" as used in this application refers to analyzing reflections of scene illumination according to the radiation's traveling time from the illuminator to the scene and back to the detector, and relating the analyzed reflections to the corresponding depth ranges in the scene from which they were reflected. In particular, the detector does not collect any information while the pulse of light is projected but only after the traveling time has passed. A single image readout from the detector (sensor) includes one or more single image sensor exposure(s), each corresponding to a different traveling time.

[0030] The terms "integration" and "accumulation" as used in this application, are corresponding terms that are used interchangeably and to the collection of the output signal over the duration of one or more time intervals.

[0031] With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0032] Before at least one embodiment of the invention is explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

[0033] Methods and systems are provided, which illuminate a scene with pulsed patterned light having one or more spatial patterns; detect reflections of the pulsed patterned light from one or more depth ranges in the scene, by activating a detector for detecting the reflections only after respective traveling times of the illumination pulses, which correspond to the depth ranges, have elapsed; and derive an image of the scene from the detected reflections and according to the spatial patterns. The methods and systems integrate gated imaging and structured light synergistically to provide required images which are differentiated with respect to object ranges in the scene and different patterns applied with respect to the objects and their ranges. Methods and systems may be optionally configured to provide images of the scene, to operate in daytime and/or in nighttime, to operate in inclement weather (rain, snow, smog, dust, etc.) and/or to operate from static and from moving platforms.

[0034] Figure 1 is a high level schematic block diagram of a system **100** for imaging a scene **90**, according to some embodiments of the invention. System **100** comprise an illuminator **110** configured to illuminate scene **90** with pulsed patterned light having a specified spatial pattern **111** (shown schematically in **Figure 1**), a detector **120** configured to detect reflections **118** from scene **90** of the pulsed patterned light, and a processing unit **130** configured to derive an image of at least a part of scene **90** within a specified range, from detected reflected patterned light pulses having a traveling time **112** that corresponds to the specified range (e.g., $T_{OFF} \equiv \Delta t = \frac{2dn}{c}$ with d the range and c the speed of light, n the index of refraction of an optical medium or $[T_{OFF} = \frac{2d_1 n}{c}] \leq \Delta t \leq [\frac{2d_2 n}{c} \approx \min(T_{LASER}, T_{II})]$ for the span of traveling time between ranges d_1 and d_2) and according to spatial pattern **111**. It is noted that different patterns may be detected from different ranges, both due to spatial expansion of the pattern with range and possibly due to different illuminated patterns detected at different ranges, as explained in more detail below. Illumination and detection may be multispectral (i.e., the gated imaging may be applied in a multispectral manner). In certain embodiments, system **100** may further comprise a database **105** that relates patterns to objects, with processing unit **130** further arranged to select, using database **105**, the illumination pattern according to objects identified in the derived image and control illuminator **110** accordingly. Database **105** may comprise different objects, their characteristics (e.g., forms, reflectivity parameters) as well as correlations between objects and patterns, such as selected patterns for different objects and expected object signals for different patterns. Processing unit **130** may use database **105** to actively analyze the scene by searching for or verifying specific objects according to the expected signals for the illuminated patterns and by illuminating the scene with patterns corresponding to existing or expected objects, in relation to database **105**.

[0035] System **100** may be associated with any type of vehicle, such as vehicles moving on roads, in air, on and in water etc. System **100** may be attached to a vehicle, mounted on a vehicle or integrated in a vehicle. System **100** may be associated with the vehicle at one or more locations, e.g., any of its front, back, sides, as well as top and down surfaces (e.g., for airborne or underwater vehicles). System **100** may interact (e.g., via a communication module) with external sources of information providing e.g., maps and information regarding traffic signs and traffic light, as well as with vehicle internal sources of information providing system **100** vehicle-related information such as speed, the angle of the axles, its acceleration, temporal information and so forth.

[0036] In certain embodiments, system **100** may comprise illuminator **110** configured to illuminate scene **90** with pulsed patterned light having at least one specified spatial pattern, detector **120** configured to detect reflections from the scene of the pulsed patterned light, and processing unit **130** configured to derive three dimensional (3D) data of at least a part of scene **90** within a plurality of ranges, from detected reflected patterned light pulses having traveling times that correspond to the specified ranges and according to the at least one spatial pattern. The 3D data may correspond to data requirements of an autonomous vehicle on which system **100** is mounted. The 3D data may be derived by system **100** as sole output or in addition to image(s) of the scene. For example, the 3D data may comprise a cloud of points, each with depths or distances provided by system **100**. System **100** may be configured to provide varying resolution of the points in the clouds, depending on the patterns used. System **100** may be configured to provide as 3D data a grid of distances which may be classified to detected objects. Certain object minimal dimensions may be defined and provided to system 100 as minimal object size detection threshold, according to which pattern parameters may be adapted.

[0037] Detector **120** may have a mosaic spectral pattern array (e.g., a two by two or any other number of repeating sub pixels that are repeated over the pixelated array of imaging sensor **120**), which is constructed and operates in accordance with some embodiments of the present invention. The spectral pattern array may have a visible and NIR spectral response that provides a signal of illumination pattern **111** and also provides a signal due to ambient light.

[0038] The illumination and detection are illustrated schematically in **Figure 1** by respective arrows and the depth of scene **90** is indicated by an axis, with specified ranges marked thereupon. It is noted that the specified range denotes a section of scene **90** along the depth axis, which may have defined starting depth and end depth. The travelling time of an illumination pulse may be calculated geometrically – for a non-limiting radial case as 2r/c (r being the range and c being the speed of light in air, neglecting the index of refraction of the optical medium) so that for detecting reflected illumination from a specified range between r_1 and r_2, reflected illumination detected between $2r_1/c$ and $2r_2/c$ after the respective illumination pulse is used to provide the respective image part (such synchronization between the illumination source and the detection means is referred to as gated imaging). For example, the specified range may be defined to include objects **95A** and/or **95B** in scene **90**.

[0039] In certain embodiments, illuminator **110** may be configured to illuminate scene **90** with pulsed patterned light having a specified spatial pattern **111** in a forwards direction, a backward direction, a rotating mode or in an envelope of a full hemisphere (360°, 2π), of half a hemisphere (180°, π), or of any other angular range around system **100**. The spatial extent of the illumination may be modified according to varying conditions.

[0040] In certain embodiments, processing unit **130** may be further configured to calculate the traveling time geometrically with respect to the specified range. Processing unit **130** may be further configured to control detector **120** and trigger or synchronize detector **120** for detecting the reflection only after the traveling time has elapsed from the respective illumination pulse.

[0041] Processing unit **130** may be configured to operate within one or more wavelength ranges, e.g., bands in infrared and/or visible ranges, provide correlations between image parts or data in different ranges and possibly enhance images and/or data using these correlations.

[0042] **Figure 2A** is a high level flowchart illustrating optional uses of system **100**, according to some embodiments of the invention. When depth information is required for the scene (**141**), corresponding patterns may be introduced and analyzed (**140**) and gated imaging may be applied (**150**) for the depth analysis (gated imaging may be applied also when no depth information is required, e.g., to exclude background noise). When the patterns are detected in the image frame (**142**), objects are detected in the depth range (**181**) and depth ranges may be correlated with any of the gated image(s) and patterns (**191**). In case pattern(s) are not identified in the frame, corrections may be made for the possibility that the object has a low reflectivity (**182**), e.g., by enhancing detector sensitivity or modifying the pattern and/or gating parameters; and if the corrections do not yield objects in the depth range, it may be concluded that no object is the depth range(s) (**183**).

[0043] System **100** synergistically combines structured light and gated imaging technologies to yield reciprocal enhancement of the yielded images and data. **Figure 2B** is a high level schematic block diagram illustrating synergistic effects of structured light and gated imaging employed by system **100**, according to some embodiments of the invention. **Figure 2B** schematically illustrates direct combinations of structured light and gated imaging (middle section) as well as complementary use of gated imaging to enhance structured light approach (upper section) and complementary use of structured light approach to enhance gated imaging (lower section). Using structured light is represented by structured light pattern generator **140** which may be part of processing unit **130** (or of illuminator **110**), while using gated imaging is represented by corresponding element **150** which may be implemented by the control of detector **120** with respect to illuminator **110** by processing unit **130** or in detector **120** itself. The arrows denote various combinations of structured light **140** and gated imaging **150**, according to some embodiments of the invention. Such combinations illustrated in **Figure 2B** are specified and exemplified below.

[0044] Figure 3A is a high level schematic illustration of a part of illuminator **110**, according to some embodiments of the invention. Illuminator **110** may comprise an array of emitters **113** as part of a die **114** which may be straight, uneven or curved. Illuminator **110** may comprise optical element(s) **116** (e.g. lens(es), prism(s) and/or beam splitter(s)) that in coordination with the form of die **114** yield specific patterns at specific directions **117**. Die **114** may be formed to yield illumination along specified direction(s) **117** and optical element(s) **116** may be controlled and move along the optical axis to enlarge, shape, focus or defocus patterns **111**. Illuminator **110** may be configured to provide illumination patterns as well as illumination for gated imaging at different rates. It is noted that illuminator **110** may be implemented using any kind of light source, in any wavelength range. Array of emitters **113** may comprise a homogenous distribution of emitters or a non-homogeneous distribution of emitters comprising some areas with a higher density of emitters and other areas with a lower density of emitters.

[0045] Illuminator **110** may be embodied as a semiconductor light source (e.g., a laser). Possible semiconductor light sources may comprise at least one vertical-cavity surface-emitting laser

(VCSEL) (e.g., a single emitter or an array of emitters), at least one edge-emitting laser (e.g., a single emitter or an array of emitters), at least one quantum dot laser, at least one array of light-emitting diodes (herein abbreviated LEDs) and the like. Illuminator **110** may have one central wavelength or a plurality of central wavelengths. Illuminator **110** may have a narrow spectrum or a wide spectrum. Illuminator **110** may also be embodied as an intense pulsed light (herein abbreviated IPL) source. Illuminator **110** may comprise multiple types of light sources; one type of light source for active gated imaging (e.g., VCSEL technology) and another type of light source for pattern **111** (e.g., edge emitter).

[0046] Referring to **Figure 2B**, as patterns illuminated on the scene by structured illumination **140** change geometrically over the scene (**160**), these changes may be detected and analyzed with respect to depth ranges in the scene by gated imaging **150** to provide an analysis of the pattern changes (**165)** at different ranges and corresponding to different objects. **Figure 3B** schematically illustrates pattern changes at different depth ranges, according to some embodiments of the invention. An illuminated pattern **111** expands spatially with the distance from illuminator **110** (e.g., the pattern's pitch increases from p_1 to p_2 upon illuminating objects at ranged d_1 and d_2 respectively) and is reflected differently from objects at these ranges. Processing unit **130** may be further configured to derive the image under consideration of a spatial expansion of the pattern at the specified range. In certain embodiments, processing unit **130** may be configured to compensate for reduced spot uniformity or enhance spot uniformity with increasing range. In certain embodiments, patterns may be generated to maintain certain pattern characteristics **170** at different distances from illuminator **110** and thus normalize the image for depth using gated imaging **150**. For example, returning to **Figure 3B**, illuminator **110** may additionally produce a denser pattern (not illustrated) which has a pitch p_1 at distance d_2.

[0047] Referring to **Figure 2B**, in certain embodiments, pattern characteristics may be adapted to identified or expected objects (**175**). **Figures 4A** and **4B** schematically illustrate pattern adaptations according to some embodiments of the invention. **Figures 5A-5H** below present additional pattern configurations. In certain embodiments, adaptations **175** may be carried out with respect to the depth of the objects. For example, **Figure 4A** schematically illustrates pattern **111B** which is added to or adapted from pattern **111A** to enable better characterization of object **95** at a specified range. In the illustrated non-limiting case, adaptation **175A** comprises additional perpendicular pattern elements to improve coverage of object **95** at the specified range. In certain embodiments, adaptations **175** may be carried out with respect to the depth of the objects. For example, **Figure 4B** schematically illustrates patterns **111A**, **111B**, **111C** which are adapted according to identified types of objects **95A**, **95B** and **95C** respectively. In the illustrated non-limiting case, adaptation **175B** comprises different pattern elements, and/or different pattern characteristics to improve coverage of corresponding objects **95A**, **95B** and **95C**. Processing unit **130** may be further configured to control the pattern illuminated by illuminator **110**.

[0048] In certain embodiments, illuminator **110** may be configured to illuminate scene **90** with a plurality of patterns **111**, each pattern **111** selected by processing unit **130** according to imaging requirements at respective specified ranges. Processing unit **130** may be further configured to adjust at least one consequent pulse pattern according to the derived image from at least one precedent pulse and with respect to parameters of objects **95** detected in the derived image. Processing unit **130** may be arranged to configure the illuminated pattern according to the specified range.

[0049] In certain embodiments, different patterns **111** may be at least partially spatially complementary in order to accumulate image information from different regions in the scene illuminated by the different patterns. In certain embodiments, complementary patterns **111** may be employed when system **100** is static. In certain embodiments, when using a single pattern, the motion of system **100** may effectively provide complementary illumination patterns resulting from the motion of the illuminated pattern.

[0050] In certain embodiments, pattern changes may be implemented by changing a clustering of illumination emitting area in illuminator **110** (e.g., when using addressable emitters and/or emitter clusters within LED or Laser illuminator **110**), or by changing an electro-optical element and/or a mechanical element applied in illuminator **110**. In certain embodiments, illuminator **110** may be configured to move or scan at least one pattern across a specified section of scene **90**, e.g., move a line pattern type stepwise across the scene section to yield a pattern having multiple lines (see e.g., **Figure 12B** below).

[0051] **Figures 5A-5H** schematically illustrate various patterns **111**, according to some embodiments of the invention. Specific patterns **111** may be selected according with respect to various parameters such as illumination conditions, gating parameters, scene parameters, expected and/or detected objects in the scene, predefined criteria (e.g., virtual fences) etc. **Figures 5A-5H** are non-limiting, and merely demonstrate the diversity of applicant patterns **111**. **Figure 5A** schematically illustrates a uniform pattern **111** of similar, round dots **171** as elements **171** in pattern **111**. **Figure 5B** schematically illustrates a non-uniform pattern **111** of similar, round dots **171**, in which the density of dots **171** changes across pattern **111**, e.g., fewer dots **171** are present at the periphery of pattern **111** and/or regions without dots **171** are part of pattern **111**. For example, regions of pattern **111**, in which more important objects are expected, may present a higher density of dots **171** in pattern **111**. **Figure 5C** schematically illustrates a uniform pattern **111** of similar, elliptic dots **171** – the form of dots **171** may be shaped according to expected objects of detection, scene characteristics etc. **Figure 5D** schematically illustrates a non-uniform pattern **111** of similar, elliptic dots **171**, in which the density of dots **171** changes across pattern **111**, e.g., fewer dots **171** are present at the periphery of pattern **111** and/or regions without dots **171** are part of pattern **111**. It is noted that different dot distributions and/or shapes may be used in different directions (e.g., x and y perpendicular directions, radial and tangential directions, etc.). **Figure 5E** schematically illustrates a non-uniform pattern **111** of different, elliptic dots **171**, in which both the density and the shape of dots **171** change across pattern **111**, e.g., fewer dots **171** are present at the periphery of pattern **111** and/or regions without dots **171** are part of pattern **111**, as well as the shape of the dots varying within pattern **111**, in the illustrated case dot orientation is partially modified in the center of pattern **111**. **Figures 5F** and **5G** schematically illustrate non-uniform patterns **111** of different, round dots **171**, in which both the density and the shape of dots **171** change across pattern **111**, e.g., smaller dots **171** are located in the center of pattern **111** while larger dots **171** are located at the periphery of pattern **111**, in the illustrated case only at the top and sides of the pattern's periphery. The size, density and shape of dots **171** may be modified to provide required resolution across different regions of pattern **111**. **Figure 5F** schematically illustrates two dot sizes while **Figure 5G** schematically illustrates a gradual change in dot size towards the periphery of pattern **111**. Finally, **Figure 5H** schematically illustrates a combination of different dot sizes and lines as elements **171** in pattern **111**. Any design of pattern **111**, comprising differently shaped elements **171** may be used, possibly multiple different patterns may be projected on different regions of the scene. It is emphasized that **Figures 5A-5H** merely provides exemplary pattern designs and do not exhaust the range of possible patterns applicable in the present invention.

[0052] In certain embodiments, pattern **111** may exhibit various symmetries, e.g., reflection symmetry with respect to a specified line and/or a specified point in pattern **111**. In certain embodiments, pattern **111** may be projected in a collimated manner to maintain the size of elements **171** at different depths in the scene. In certain embodiments, pattern **111** may a multitude of elements **171** characterized by a coded distribution, e.g., in a speckle pattern.

[0053] **Figure 6** is an exemplary illustration of images **125A-125C** derived by system **100**, according to some embodiments of the invention. **Figure 6** illustrates a daytime scene with system **100** located on a static vehicle. The scene consists of three objects ("pedestrians") on the right side (using laminated wood with clothing), every few meters there are retro-reflectors on the ground (right-side), and on the left side are parked vehicles. Images **125A-125C** were taken with the same detector **120** (gated CMOS image sensor). Image **125A** is a regular daytime image of scene **90**, without using illuminator **110** to illuminate the scene. Illumination patterns **111** used in image **125B** are multiple, each having a narrow depth of field (DOF) of about 20m and image **125B** is a depth map, visually illustrating in gray scale the different depth ranges from which the image is composed. At each depth range different patterns may be allocated, or pattern behavior at the specific ranges may be analyzed. Furthermore, patterns may be used to enhance depth estimation within the depth range (according to the detected reflections) and patterns may be selected with reference to objects detected at each depth range. Processing unit **130** may be further configured to subtract a passively sensed image from the derived image. Image **125A** may be subtracted from the derived image (using gated structured light) or any other image to remove or attenuate background noise and enhance depth related information, as demonstrated in derived image **125C**, being in this case a gated image as the pattern used is a narrow DOF, in which objects are very clearly distinguished from their surroundings. Image **125A** may have a similar exposure time or a different exposure time with respect to the exposure time of images **125B** or **125C**. Image **125A** may be generated by a single exposure event per an image readout or by multiple exposures per an image readout. In the illustrated case, image **125A** is subtracted from both images **125B**, **125C**. This approach may be applied at nighttime as well, e.g., to reduce the ambient light. Typically, background image reduction may improve the signal to background ratio in daytime and the signal to noise ratio in nighttime. It is noted that the subtraction or attenuation may be applied to part(s) of the image as well as to the whole image.

[0054] In certain embodiments, processing unit **130** may be arranged to derive the image by accumulating scene parts having different specified ranges. In certain embodiments, processing unit **130** is further configured to remove image parts corresponding to a background part of scene **90** beyond a threshold range. Deriving images, image parts defined by depth ranges may be selected according to their relevance, as defined by corresponding rules. Processing unit **130** may use different types of image frames for feature extraction.

[0055] In certain embodiments, system **100** may be used for Advanced Driver Assistance Systems (ADAS) features such as: Lane Departure Warning (LDW), Lane Keeping Assist (LKA), Adaptive Headlamp Control (AHC), Traffic Sign Recognition (TSR), Drowsy Driver Detection (DDD), Full Adaptive Cruise Control (ACC), Front Collision Warning (FCW), Automatic Emergency Braking (AEB), ACC Stop & Go (ACC S&G), Pedestrian Detection (PD), Scene Interpretation (SI), Construction Zone Assist (CZD), Road Preview-Speed bump, and pot holes detection (RP), Night Vision Performance (NV), animal detection and obstacle detection. In certain embodiments, system **100** may be used for auto-pilot features or autonomous vehicles. Processing unit **130** may be configured to provide alerts concerning detected situations or conditions, e.g., certain dangers or, in case of autonomous vehicles, of underperformance of vehicle sensing systems.

[0056] Referring to **Figure 2B**, structured illumination **140** may implement pattern changes over the scene **160** which may be analyzed with respect to depth ranges in the scene by gated imaging **150** to provide an analysis of different patterns at different ranges. In certain embodiments, gated imaging **150** may be used to define depth regions **180** in scene **90** and structured light generator **140** may be used to define patterns that correspond to the defined depth regions **190** to enhance imaging (e.g., provide more details on certain defined regions or less details on other defined regions). Using gated imaging **150** adaptive virtual fences **195** may be applied by generator **140**, i.e., the illuminated patterns may be adapted and spatially defined to provide images or imaging data for controlling movement through specified regions. For example, in an automotive context, adaptive virtual fences **195** may be set at regions from which objects are expected (e.g., at cross roads, or between parking cars) to enhance monitoring these regions and provide early alarms.

[0057] **Figures 7A** and **7B** are high level schematic illustrations of scene **90** with applied adaptive virtual fences **195**, according to some embodiments of the invention. Virtual fences **195** may be defined using one or more combinations of pattern **111** and range to enable reference to specifically defined two or three dimensional region which is, e.g., as in **Figure 7A**, delimited between the respective ranges and possibly by specific illuminated pattern characteristics and possibly additional cues (e.g., objects detected in the image); or, e.g., as in **Figure 7B**, encloses system **100**, mounted e.g., on an autonomous vehicle. In the non-limiting example of **Figure 7A**, virtual fences **195** may be set between trees and along the center line to detect and provide warnings concerning objects, e.g., crossing objects. In the non-limiting example of **Figure 7B**, one or more circumferential virtual fences **195** may be projected to surround the vehicle with system **100**, and intrusions through virtual fence **195** may be monitored in more detail, e.g., using specified patterns and/or gating parameters (**196**). It is noted that virtual fences **195** may be defined at any one or multiple ranges with respect to system **100** and cover any angular range (full circumference to narrow angle), possibly depending on the specific ranges and possibly dynamically modified, particularly in case of autonomous vehicle applications. Clearly, when system **100** is employed from a moving vehicle, continuous spatial updating of the locations of virtual fences **195** is carried out according to the changing geometry of scene **90** as perceived from the moving vehicle.

[0058] Object detection may be carried out according to shape parameters, reflectivity parameters or any other object defining parameters. In certain embodiments, processing unit **130** may be configured to detect moving objects in scene **90**, e.g., according to changes in the reflected patterns and/or according to changes in the depth range data related to the objects.

[0059] Figures 8A and **8B** are high level schematic illustrations of detector **120**, according to some embodiments of the invention.

[0060] Figure 8A schematically illustrates conceptual configurations of detector pixels **128**, comprising a photosensor **121** connected via a gating control **124** to an integration element, both latter elements being with an accumulation portion **122**. The accumulated signal is then delivered to a readout portion **126** which provides the pixel readout. Photosensor **121**, accumulation portion **122** and readout portion **126** may be reset by corresponding controls **121A** and **126A**.

[0061] Photosensor **121** outputs a signal indicative of an intensity of incident light. Photosensor **121** is reset by inputting the appropriate photosensor reset control signal. Photosensor **121** may be one of the following types: photodiodes, photogates, metal-oxide semiconductor (MOS) capacitors, positive-intrinsic-negative (PIN) photodiodes, a pinned photodiodes, avalanche photodiodes or any other suitable photosensitive element. Some types of photosensors may require changes in the pixel structure.

[0062] Accumulation portion **122** performs gated accumulation of the photosensor output signal over a sequence of time intervals. The accumulated output level may be reset by inputting a pixel reset signal into accumulation portion **122** (not illustrated). The timing of the accumulation time intervals is controlled by a gating control signal, as described below.

[0063] Figure 8B schematically illustrates a "gate-able" pixel schematic **128** that may be provided by Complementary Metal Oxide Semiconductor (CMOS) standard fabrication technology, according to some embodiments of the invention. **Figure 8B** is a non-limiting example for the design illustrated in **Figure 8A**. Each pulse of light (i.e., each gate) is converted to a proportional electrical signal by the Photo-Diode (PD) **121** that may be a pinned PD **121** (as an example for photosensor **121** in **Figure 8A**). The generated electrical signal from the PD is transferred by an electric field to the Floating Diffusion (FD)/ Memory Node (MN) **123** which acts as an integrator **122** (i.e., a capacitor) accumulating each converted pulse of light (as an example for accumulation portion **122** in **Figure 8A**). Two controllable pixel signals generate the pixel gate **-** the transfer gate transistor (TX1) **124** (as an example for gating control **124** in **Figure 8A**) and the anti-blooming transistor (TX2) **121A** (as an example for reset control **121A** in **Figure 8A**). The anti-blooming transistor has three main objectives; the first being part of the single light pulse gating mechanism when coupled to TX1 (i.e., TX2 is turned from ON to OFF or TX2 is turned from OFF to ON), the second preventing undesired parasitic signal generated in the PD not to be accumulated in the PD during the time TX1 is OFF (i.e., PD Reset) and the third to channel excessive electrical signal originated in the PD when TX1 is ON, hence the role of anti-blooming. Anti-blooming TX2 controllable signal acts as an optical shutter which ends the single accumulated light pulse. Transfer gate transistor (TX1 **124**) is turned ON only in a desired time and only for a desired duration which is coupled to TX2 **121A**. Once all pulses of light were accumulated in the FD/MN **123**, the signal is readout to provide a single image frame.

[0064] Multiple gated low noise pixels may have a standard electric signal chain after the "gate-able" configuration of PD **121**, TX1 **124**, TX2 **121A** and FD/MN **123**. This standard electric signal chain may consist of a Reset transistor (RST) **126A** (as an example for readout reset control **126A** in **Figure 8A**) with the role of charging FD/MN **123** with electrical charge using the pixel voltage (VDD) or other voltage span, may consist of a Source Follower (SF) transistor **127** converting the accumulated signal (i.e., electrons) to voltage and may consist of a Select (SEL) transistor **127A** connected to the column and/or row **129A** for a pixel array.

[0065] This schematic circuit diagram depicting a “gate-able" pixel has a minimal of five transistors (“5T”). This pixel configuration may operate in a “gate-able" timing sequence. In addition this pixel may also operate in a standard 5T pixel timing sequence (such as Global Shutter pixel) or operate in a standard 4T pixel timing sequence. This versatile operating configuration (i.e., gating sequence or standard 5T or standard 4T) enables to operate the pixel under different lighting conditions. For example, gating timing sequence during low light level in active gated mode (with gated illumination), 4T timing sequence during low light level during nighttime (without illumination) and 5T timing sequence during high light level during daytime.

This schematic circuit diagram depicting a “gate-able" pixel may also have additional circuits for internal Correlated Double Sampling (CDS) and/or for High Dynamic Range (HDR). Adding such additional circuits reduces the photo-sensing fill factor (i.e., sensitivity of the pixel). Pixel **128** may be fabricated with a standard epitaxial layer (e.g., 5µm, 12µm) or higher epitaxial layer (e.g., larger than 12µm). In addition, epitaxial layer may have a standard resistivity (e.g., a few ohms) or high resistivity (e.g., a few kilo-ohms).

[0066] Figures 9A and **9B** schematically illustrate related temporal sequences of illumination and detection, according to some embodiments of the invention. **Figure 9A** schematically illustrates temporal sequences of illumination and detection, according to some embodiments of the invention. Gated detector **120** may have multiple gates (denoted by “G” for detector gating) with different length time exposures **135** marked 1, 2, ..., M (i.e., $\mathbf{135_1}$, $\mathbf{135_2}$, ..., $\mathbf{135_M}$) in different timing sequence **136** marked 1, 2, ..., M (i.e., $\mathbf{136_1}$, $\mathbf{136_2}$, ..., $\mathbf{136_M}$) per detector image frame **137A** readout (image frame readout duration is not illustrated). Frame **137A** may be used as a “passive” detection frame **137A** (similar to image **125A** in **Figure 6**) in association with “active” detection frames **137B** in which illuminator **110** applies illumination pulses. Active frame **137B** may have a timing sequence: illumination pulse **115** followed by a certain delay **138** with a detector exposure **135** to implement gating. Illumination pulses **115** (denoted by “L” for laser) may have a different duration marked 1, 2, ..., N (i.e., $\mathbf{115_1}$, $\mathbf{115_2}$, ..., $\mathbf{115_N}$), each followed by a certain delay **138** marked 1, 2, ..., N (i.e., $\mathbf{138_1}$, $\mathbf{138_2}$, ..., $\mathbf{138_N}$) correlating to different T_{OFF} values. Detector **120** different exposure durations **135** marked 1, 2, ..., N (i.e., $\mathbf{135_1}$, $\mathbf{135_2}$, ..., $\mathbf{135_N}$) in different timing sequence **136** marked 1, 2, ..., N (i.e., $\mathbf{136_1}$, $\mathbf{136_2}$, ..., $\mathbf{136_N}$) up to N cycles per detector image frame **137B** readout (image frame readout duration is not illustrated). Different length time exposures **135** and illumination pulses **115** duration correlating to different T_{LASER} and T_{II} values.

[0067] Figure 9B schematically illustrates a generalized temporal sequence of illumination and detection, according to some embodiments of the invention. A specific pattern may comprise any number of elements from the generalized pattern illustrated in **Figure 9B**. A first phase “1” may comprise one or more cycles 1_1, 1_2...1_Q of any number of pairs of illumination with one or more patterns **111** and gated detection, each cycle followed by a corresponding readout of the sensor. Illumination and detection periods may be short and/or relate to specific regions in the scene (e.g., directing specific patterns at specific regions). A second phase “2” may comprise one or more cycles 2_1,...2_J of any number of pairs of illumination (without patterns **111**) and gated detection, each cycle followed by a corresponding readout of the sensor. Illumination and detection periods may be longer than in the first phase. Gating parameters may be at least partially determined with respect to readouts from the first phase. A third phase “3” may comprise one or more cycles $3_1,...3_R$ of any number of detection (gated or not gated) without active illumination, each cycle followed by a corresponding readout of the sensor. Illumination and detection periods may be longer than in the second phase. Sensor (detector) **120** readout method may be different as describe herein below between types of frames (e.g., $1_1..1_Q$, $2_1..2_J$ and $3_1..3_R$).

[0068] In gated camera as detector **120**, such as that based on a Gated CMOS Imager Sensor ("GCMOS") and alike, gating (light accumulation) timing may be different from each pixel to another or from each array (several pixels or pixels cluster) to another in the GCMOS. The illustrated method enables each gated pixel (or gated array) to accumulate different DOF's (depth of focus "slices", or depth ranges), accomplished by controlling each pixel or pixels cluster triggering mechanism. The illustrated gated imaging system may overcome the problems of imaging sensor blooming during high intensity ambient light level (e.g., during daytime, high or low front headlight of incoming vehicle during nighttime etc.) by short gates (i.e., exposure time\light accumulating) of the gated camera which are directly related to lowering the numbers of gates per image frame readout and/or narrowing the gates length time and/or lowering the gated camera gain. In certain embodiments, blooming may also be dealt with in the gated camera, such as GCMOS and alike, by a high anti-blooming ratio between each pixel to another (i.e., reducing signal diffusion overflow from pixel to neighboring pixel). For example, detector **120** may enable a dynamic range of 110dB between frame to consecutive frame where the first frame has a single exposure of 50nsec and the consecutive frame has a single exposure of 16msec.

[0069] In order to exemplify the efficiency and sensitivity of proposed system **100** and method **200**, the following calculation is presented. Assumptions:

<u>Detector Lens</u>

Transmittance of optics T_{optics}=0.9; Target reflectivity r_{target}=0.3; Lens F-number F#=1.2, λ=808nm. Lens diameter D=23mm.

<u>Detector **120**</u>

GCMOS (gated complementary MOS- metal–oxide–semiconductor) sensor, pitch (pixel dimension) d=10μm, Quantum efficiency QE=0.45, Sensitivity=$QE \cdot q_{electron} \cdot \lambda / hc$=0.293A/W (ampere to watt). For a 1.2Mpixel detector with $Pixels_{horizontal}$=1280, the instantaneous field of view IFOV= $\theta_{laser,\ h(horizontal)}/Pixels_{horizontal}$ = 0.327mrad.

<u>Illuminator **110**</u>

Laser peak power, P_{laser}=500W, illuminator lens transmission τ_{laser}=0.9, $\theta_{laser,\ h(horizontal)}$=24°, $\theta_{laser,\ v(vertical)}$=8°, pulse length T_g=10ns, Pulse shape factor η=0.99, dot divergence $D_{dot,v(vertical)}$=0.5°, $D_{dot,h(horizontal)}$=0.5°, thus Number of dots $N_{dots}= \theta_{laser,\ h}/ D_{dot,h} \cdot \theta_{laser,\ v}/D_{dot,v}$ = 768 with laser power per dot $P_{spot}= P_{laser}/N_{dots}$=0.651W.

<u>Atmospheric conditions</u>

Visibility Vis=12km, height from sea level H=100m.

$Kh=0.96\cdot\exp(-(H/3)\cdot 0.132\cdot 10^{-3}/ft)=0.946$

Attenuation coefficient $\gamma=-\ln(0.02)/Vis \cdot (\lambda/0.55\mu)^{-1.3}\cdot Kh=0.187\ km^{-1}$

<u>Typical signal per pixel</u>

Measured as the number of electrons reflected and received at the pixel per laser pulse (i.e., per gate signal), and calculated as: Electrons per gate = $Sensitivity\cdot P_{spot}\cdot\ \tau_{laser}\cdot\ (T_{optics}\cdot\ r_{target}\cdot e^{-2\gamma R}/4R^2)\cdot\eta\cdot T_g\cdot D^2\ /q_{electron}$ = (at R=150m) **11 electrons**.

<u>Typical noise</u>

Typical noise from solar radiation (daytime) at the respective wavelength, for solar irradiance Isun=800W/$m^2\mu$ at filtered wavelength Filter=30μ, calculated as: $Electrons_{sun}$ per gate = $sensitivity\cdot(I_{sun}\cdot\tau_{laser}\cdot Filter/\pi)\cdot(T_{optics}\cdot\ r_{target}/4F\#^2)\cdot\eta\cdot T_g\cdot d^2\ /q_{electron}$ = **0.6 electrons**.

Hence, the captured signal is significantly larger than the background noise.

[0070] Figures 10A-10D schematically illustrate the pixel array of detector **120**, according to some embodiments of the invention. In certain embodiments, pixel array **120** comprises N columns **129A** and M rows **129B** of pixels **128**, and is commonly read row-wise. In certain embodiments, incremental, controllable delays **131** may be introduced between rows, (x-1)τ delay for the x^{th} row **129B** (**Figure 10A**). Incremental delays **131** may be introduced for row groups under any grouping (e.g., adjacent rows having the same delay, alternating rows having the same delay, or the same delay repeating every specified number of rows, as non-limiting examples). Controllable delays **131** may be implemented by a capacitor or by any other delay means to delay the triggering propagation signal of the detector rows. This delay provides a different T_{OFF} between the detector rows. After the exposure(s), the readout process is performed.

[0071] In certain embodiments, a readout process is provided in detector **120** of **Figures 10B-10C**. In stage **132A**, certain pixels **128** may form clusters **127A**, **127B** and **127C** per a single image-frame. For example, the clusters may correspond to reflections of illuminated pattern **111** and/or to reflections from a specified depth range defined by the gating timing. In certain embodiments, pixels **128** and/or clusters **127A**, **127B**, **127C** may be directly addressable and readout. In a second stage **132B** of the readout process (**Figure 10C**), pixels **128** and/or clusters **127A**, **127B** and **127C** may be collected by another block (not illustrated) where in only the relevant columns (with the pattern data) are transferred to next stage of the readout process to yield faster readout (e.g., not reading columns with no or negligible pixel signal). Stages **132A, 132B** may be configured to provide a faster readout mechanism of the image sensor (for the pattern frame) to minimize the readout time and minimize the required bandwidth.

[0072] Figure 10D schematically illustrates handling pixel array **120** by implementing readout in the relevant rows/columns **131A**, **131B** (using parallel ADC). Each pixel has ADC circuit so that it is able to make use of two dimensional nature of image signal. Therefore the processing is very fast. This architecture has the disadvantages of the low fill factor and high power dissipation while it provides a short readout time and fast readout.

[0073] In certain embodiments, a readout process may be provided in detector **120** for a fixed pattern distribution in the detector plane, which may be implemented in the following steps: Step 1) Setup - configuring the map locations in the detector array **120** wherein the pattern is reflected. Step 2) exposing the detector **120** array as describe above. Step 3) Readout image (or part of the image) of the locations in the detector array **120** wherein the pattern is reflected by using the map locations. The readout process may be implemented by a "handshake" between the detector **120** to the processing unit **130** using the map location whereas a detector wishes to read a row it sends a message or any other flag to the processing unit **130** and the processing unit **130** replays if this row should be read ("Valid Row"). Whereas a row without any relevant data (i.e., no reflected pattern) may not be read, hence the processing unit **130** replays ("False Row") and the detector skips this row to the next one. This proposed method reduces the number of rows to read and may have a faster framerate (versus reading the entire detector array) using a "standard" slow readout channel. For example - a detector having 1280 X 960 pixels, 10bit, row readout of 4.25us with a 4 LVDS data outputs, each running at 800Mbps, plus 2 LVDS ports for clock recovery and image synchronization could provide a full image readout of 4.08ms in the prior art. Advantageously, implementing the proposed method by reducing the readout rows may reach a full image readout time of only 0.85ms (assuming 200 rows readout). Detector **120** pattern map locations may change per time or per type of pattern. Detector **120** may be configured to increase a readout frame rate by skipping empty detector rows.

[0074] In certain embodiments, a readout process is provided in detector **120** for a pattern distribution varying in the detector plane which may be implemented in the following steps: Step 1) exposing the detector **120** array as describe above. Step 2) Readout image (or part of the image) of the locations in the detector array **120** in which the pattern is reflected. The readout process may be implemented by using a row-summing detector block which provides a signal summing mechanism (or signal threshold) information. Once the signal exists in the row-summing detector block the row is valid whereas if the signal doesn't exist (no signal) in this block the row will not be readout. This proposed method reduces the amount of rows to read and may have a faster framerate (versus reading the entire detector array) using a prior art slow readout channel. For example a detector having 1280 X 960 pixels, 10bit, row readout of 4us with a 4 LVDS data outputs, each running at 800Mbps, plus 2 LVDS ports for clock recovery and image synchronization could provide full image readout of 3.84ms in the prior art. Advantageously, implementing the proposed method by reducing the readout rows may reach a full image readout time of only 0.6ms (assuming 150 rows readout). Detector **120** may be configured to increase a readout frame rate by addressing detector locations according to the illuminated specified spatial pattern.

[0075] In certain embodiments, a readout process that is provided in detector **120** may be implemented using any one of the following options: (i) using addressable pixels and/or pixel clusters, (ii) turning off or skipping columns that have no relevant data (implementing column-parallel ADC – analog to digital conversion), (iii) triggering from one side of the array (the "long part") and reading-out in a rolling shutter mode (implementing Column-parallel ADC), (iv) having another block that organizes the array prior readout and (v) skipping rows that have no relevant data (implementing map locations or row-summing block).

[0076] **Figure 11** is a high level flowchart illustrating a method **200**, according to some embodiments of the invention. Method **200** may comprise illuminating a scene with pulsed patterned light having at least one specified spatial pattern (stage **210**), detecting reflections of the pulsed patterned light from at least one specified range in the scene (stage **220**), by activating a detector for detecting the reflections only after at least one traveling time of the respective illumination pulse, corresponding to the at least one specified range, has elapsed (stage **222**), and deriving an image of at least a part of the scene within the at least one specified range, from the detected reflections and according to the at least one spatial pattern (stage **230**).

[0077] Method **200** may further comprise illuminating the scene with a plurality of patterns, each pattern selected according to imaging requirements at respective specified ranges (stage **212**). In certain embodiments, method **200** may further comprise configuring the illuminated pattern according to the specified range (stage **214**). Method **200** may comprise configuring at least some of the patterns to be spatially complementary (stage **218**). Illuminating the scene **110** and detecting the reflections **220** may be carried out by multispectral radiation (stages **216**, **224**). Method **200** may comprise carrying out the illuminating using a laser (stage **219**).

[0078] In certain embodiments, illuminating the scene **210** may be carried out by scanning a pattern element across a specified section of the scene to yield the pattern (stage **215**).

[0079] Method may further comprise detecting moving objects in the scene (stage **226**), e.g., according to detected reflections of illumination patterns with respect to their respective depth ranges.

[0080] Method may further comprise subtracting a passively sensed image from the derived image (stage **231**).

[0081] Method **200** may further comprise deriving the image under consideration of a spatial expansion of the pattern at the specified range (stage **232**). Method **200** may comprise removing image parts corresponding to a background part of the scene, e.g., beyond a threshold range (stage **234**). Method **200** may further comprise deriving the image from multiple detected reflections corresponding to different specified ranges (stage **236**).

[0082] Method **200** may further comprise increasing a readout frame rate of the detector by skipping empty detector rows (stage **238**) and/or by addressing detector locations according to the illuminated specified spatial pattern (stage **239**).

[0083] In certain embodiments, method **200** further comprises adjusting at least one consequent pulse pattern according to the derived image from at least one precedent pulse (stage **240**). Adjusting **240** may be carried out with respect to parameters of objects detected in the derived image (stage **242**). For example, adjusting **240** may be carried out by changing a clustering of illumination units or by changing a mask applied to an illumination source (stage **246**).

[0084] In certain embodiments, image derivation **230** may comprise accumulating scene parts having different specified ranges (stage **244**).

[0085] Method **200** may further comprise maintaining a database that relates patterns to objects (stage **250**) and selecting, using the database, illumination pattern(s) according to objects identified in the derived image (stage **252**).

[0086] Method **200** may further comprise calculating the at least one traveling time geometrically with respect to the corresponding specified range (stage **260**). In certain embodiments, method **200** may comprise enhancing range estimation(s) to object(s) according to the detected reflections (stage **262**).

[0087] In certain embodiments, some of the steps of method **200**, such as illuminating **210**, detecting **220** and deriving **230**, may be carried out on a moving vehicle (stage **270**) and/or by an autonomous vehicle (stage **275**).

[0088] **Figures 12A-12D** are high level schematic block diagrams of systems configurations, according to some embodiments of the invention. System **100** comprises illuminator **110** receiving power from vehicle **96** and converting the voltages and currents using a power supply **151** and communicated with processing unit **130** and/or detector **120**. Power is used by a laser controller **152** and a laser wavelength controller **152** (as an option) and via a laser module **154** to generate illumination modified by a laser optical module **155**. **Figure 12A** schematically illustrates this basic configuration, while **Figure 12B** schematically illustrates a configuration with a MEMS (microelectromechanical systems) device **156** (e.g., a DLP – a digital light processing device) for spatio-temporal control of illumination elements (e.g., pattern(s) and/or gating pulses). **Figure 12C** schematically illustrates a configuration with two laser modules **155A**, **155B** fed from single laser module **154** via corresponding beam splitters **157A**, **157B** and configured to generate separately pattern(s) **111** and gating signals **150**. **Figure 12D** schematically illustrates a configuration with two laser modules **155A**, **155B** fed from two corresponding laser module **154A**, **154B** and configured to generate separately pattern(s) **111** and gating signals **150**.

[0089] **Figures 13A** and **13B** are high level schematic illustrations of measuring vehicle distances, according to some embodiments of the invention. **Figure 13A** schematically illustrates the dependency between the range and a horizontal or height separation (H) resulting in different angles ϕ, θ from which illumination (reflections) **118A**, **118B** from different objects **95A**, **95B** (respectively) such as vehicles arrived at detector **120** such as a camera. **Figure 13B**

schematically illustrates a way to measure the angle ϕ of incoming illumination (reflections) **118** by measuring a distance Z between images of the object from which illumination (reflection) **118** is received. **Figure 13B** demonstrates that, depending on the materials that separate detector **120** from the surroundings (e.g., a layered windshield), characterized by thicknesses X, Y and refractive indices n_1, n_2, n_3, angles ϕ result in proportional distances Z which may be used to measure or verify the value of ϕ.

[0090] Advantageously, with respect to WIPO Publication No. 2015/004213, in the current invention the detector is activated only after the traveling time of the respective illumination pulse has elapsed, while WIPO Publication No. 2015/004213 teaches synchronizing the detector with the illuminator, i.e., operating them simultaneously.

[0091] Advantageously, with respect to U.S. Patent Publication No. 20130222551, in the current invention a synergistic combination of gated imaging and structured light methods is achieved during the operation of the system to derive the captured images, while U.S. Patent Publication No. 20130222551 applies temporally modulated structured light during a calibration stage to derive depth information and spatiotemporal modulation during the capturing, but does not employ gated imaging to the modulated illumination and does not employ gated imaging synergistically with structured light illumination.

[0092] In the above description, an embodiment is an example or implementation of the invention. The various appearances of "one embodiment”, "an embodiment", "certain embodiments" or "some embodiments" do not necessarily all refer to the same embodiments.

[0093] Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment.

[0094] Certain embodiments of the invention may include features from different embodiments disclosed above, and certain embodiments may incorporate elements from other embodiments disclosed above. The disclosure of elements of the invention in the context of a specific embodiment is not to be taken as limiting their use in the specific embodiment alone.

[0095] Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in certain embodiments other than the ones outlined in the description above.

[0096] The invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

[0097] Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined.

[0098] While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described, but by the appended claims and their legal equivalents.

CLAIMS

1. A method comprising:

   illuminating a scene with pulsed patterned light, the illumination pulses having at least one specified spatial pattern,

   detecting reflections of the illuminated pulsed patterned light from at least one specified range in the scene, by activating a detector for detecting the reflections only after at least one traveling time of the respective illumination pulse, corresponding to the at least one specified range, has elapsed; and for detecting the at least one specified spatial pattern of the reflections, and

   deriving an image of at least a part of the scene within the at least one specified range, from the detected reflections and according to the detected at least one spatial pattern.
2. The method of claim 1, further comprising deriving the image under consideration of a spatial expansion of the pattern at the specified range.
3. The method of claim 1, further comprising illuminating the scene with a plurality of patterns, each pattern selected according to imaging requirements at respective specified ranges.
4. The method of claim 3, wherein at least some of the patterns are spatially complementary.
5. The method of claim 1, further comprising adjusting at least one consequent pulse pattern according to the derived image from at least one precedent pulse.
6. The method of claim 5, wherein the adjusting is carried out with respect to parameters of objects detected in the derived image.
7. The method of claim 5, wherein the adjusting is carried out by changing a clustering of illumination units or by changing a mask applied to an illumination source.
8. The method of claim 1, further comprising configuring the illuminated pattern according to the specified range.
9. The method of claim 8, further comprising enhancing range estimation according to the detected reflections.
10. The method of claim 1, further comprising removing image parts corresponding to a background part of the scene beyond a threshold range.
11. The method of claim 1, further comprising subtracting a passively sensed image from the derived image.

12. The method of claim 1, further comprising maintaining a database that relates patterns to objects and selecting, using the database, the illumination pattern according to objects identified in the derived image.
13. The method of claim 1, where the image derivation comprises accumulating scene parts having different specified ranges.
14. The method of claim 1, further comprising deriving the image from multiple detected reflections corresponding to different specified ranges.
15. The method of claim 1, further comprising calculating the at least one traveling time geometrically with respect to the specified range.
16. The method of claim 1, further comprising illuminating the scene by scanning a pattern element across a specified section of the scene to yield the pattern.
17. The method of claim 1, wherein the illuminating and the detecting are multispectral.
18. The method of claim 1, further comprising detecting moving objects in the scene.
19. The method of claim 1, further comprising increasing a readout frame rate of the detector by skipping empty detector rows.
20. The method of claim 1, further comprising increasing a readout frame rate of the detector by addressing detector locations according to the illuminated specified spatial pattern.
21. The method of claim 1, further comprising carrying out the illuminating, the detecting and the deriving by an autonomous vehicle.
22. A system comprising:

an illuminator configured to illuminate a scene with pulsed patterned light, the illumination pulses having at least one specified spatial pattern,

a detector configured to detect reflections from the scene of the illuminated pulsed patterned light, and

a processing unit configured to derive an image of at least a part of the scene within at least one specified range, from detected reflected patterned light pulses having at least one traveling time that corresponds to the at least one specified range and according to the at least one spatial pattern, wherein the processing unit is further configured to control the detector and activate the detector for detecting the reflection only after the at least one traveling time has elapsed from the respective illumination pulse, and for detecting the at least one specified spatial pattern of the reflections.

23. The system of claim 22, wherein the processing unit is further configured to derive the image under consideration of a spatial expansion of the at least one pattern at the specified range.
24. The system of claim 22, wherein the processing unit is further configured to control the at least one pattern illuminated by the illuminator.
25. The system of claim 24, wherein the illuminator is further configured to illuminate the scene with a plurality of patterns, each pattern selected by the processing unit according to imaging requirements at respective specified ranges.
26. The system of claim 25, wherein at least some of the patterns are spatially complementary.
27. The system of claim 24, wherein the processing unit is further configured to adjust at least one consequent pulse pattern according to the derived image from at least one precedent pulse and with respect to parameters of objects detected in the derived image.
28. The system of claim 27, wherein the processing unit is configured to adjust the pattern by changing a clustering of illumination units in the illuminator or by changing a mask applied to the illuminator.
29. The system of claim 24, wherein the processing unit is further arranged to configure the illuminated pattern according to the specified range.
30. The system of claim 29, wherein the processing unit is further arranged to enhance range estimation according to the detected reflections.
31. The system of claim 22, wherein the processing unit is further configured to remove image parts corresponding to a background part of the scene beyond a threshold range.
32. The system of claim 22, wherein the processing unit is further configured to subtract a passively sensed image from the derived image.
33. The system of claim 22, further comprising a database that relates patterns to objects and wherein the processing unit is further arranged to select, using the database, the illumination pattern according to objects identified in the derived image and control the illuminator accordingly.
34. The system of claim 22, wherein the processing unit is further arranged to derive the image by accumulating scene parts having different specified ranges.
35. The system of claim 22, wherein the processing unit is further arranged to derive the image from multiple detected reflections corresponding to different specified ranges.
36. The system of claim 22, wherein the illuminator is configured to scan at least one pattern across a specified section of the scene.

37. The system of claim 22, wherein the processing unit is further configured to calculate the at least one traveling time geometrically with respect to the specified range.

38. The system of claim 22, wherein the detector is configured to increase a readout frame rate by skipping empty detector rows.

39. The system of claim 22, wherein the detector is configured to increase a readout frame rate by addressing detector locations according to the illuminated specified spatial pattern.

40. A system comprising a gated imaging unit which employs gated structured light comprising patterned gated pulses, for illuminating a scene and a processing unit controlling the imaging unit and configured to correlate image data from depth ranges in the scene according to gating parameters with respective image parts derived from processing of reflected structured light patterns.

41. The system of claim 40, wherein the processing unit is further configured to analyze geometrical illumination pattern changes at different depth ranges.

42. The system of claim 40, wherein the processing unit is further configured to maintain specified illumination pattern characteristics at different depth ranges.

43. The system of claim 40, wherein the processing unit is further configured to match specified illumination patterns to specified depth ranges.

44. The system of claim 40, wherein the processing unit is further configured to analyze a 3D structure of the scene from the gated imaging and allocate specified illumination patterns to specified elements in the 3D structure.

45. The system of claim 40, wherein the processing unit is further configured to monitor virtual fences in the scene using the specified illumination patterns allocated to the specified elements in the 3D structure.

46. The system of claim 40, wherein the detector is configured to increase a readout frame rate by skipping empty detector rows and/or by addressing detector locations according to the illuminated specified spatial pattern.

47. A system comprising:

an illuminator configured to illuminate a scene with pulsed patterned light, the_pulses having at least one specified spatial pattern,

a detector configured to detect reflections from the scene of the pulsed patterned light and detect the at least one specified spatial pattern of the reflections, and a processing unit configured to derive three dimensional (3D) data of at least a part of the scene within a plurality of ranges, from detected reflected patterned light pulses having traveling times that correspond to the specified ranges and according to the detected at least one spatial pattern, wherein the processing unit is further configured to control the detector and activate the detector for detecting the reflection only after the corresponding traveling time has elapsed from the respective illumination pulse,

wherein the 3D data corresponds to data requirements of an autonomous vehicle on which the system is mounted.

48. The system of claim 47, wherein the processing unit is further configured to derive an image of at least a part of the scene.

49. A method comprising:

illuminating a scene with pulsed patterned light, the light pulses having at least one specified spatial pattern,

detecting reflections of the pulsed patterned light from a plurality of ranges in the scene, by activating a detector for detecting the reflections only after traveling times of the respective illumination pulses that correspond to the specified ranges have elapsed, and detecting the at least one specified spatial pattern of the reflections, and

deriving 3D data of at least a part of the scene within the plurality of ranges, from detected reflected patterned light pulses, wherein the 3D data corresponds to data requirements of an autonomous vehicle from which the illuminating and the detecting are carried out.

50. The method of claim 49, further comprising deriving an image of at least a part of the scene.

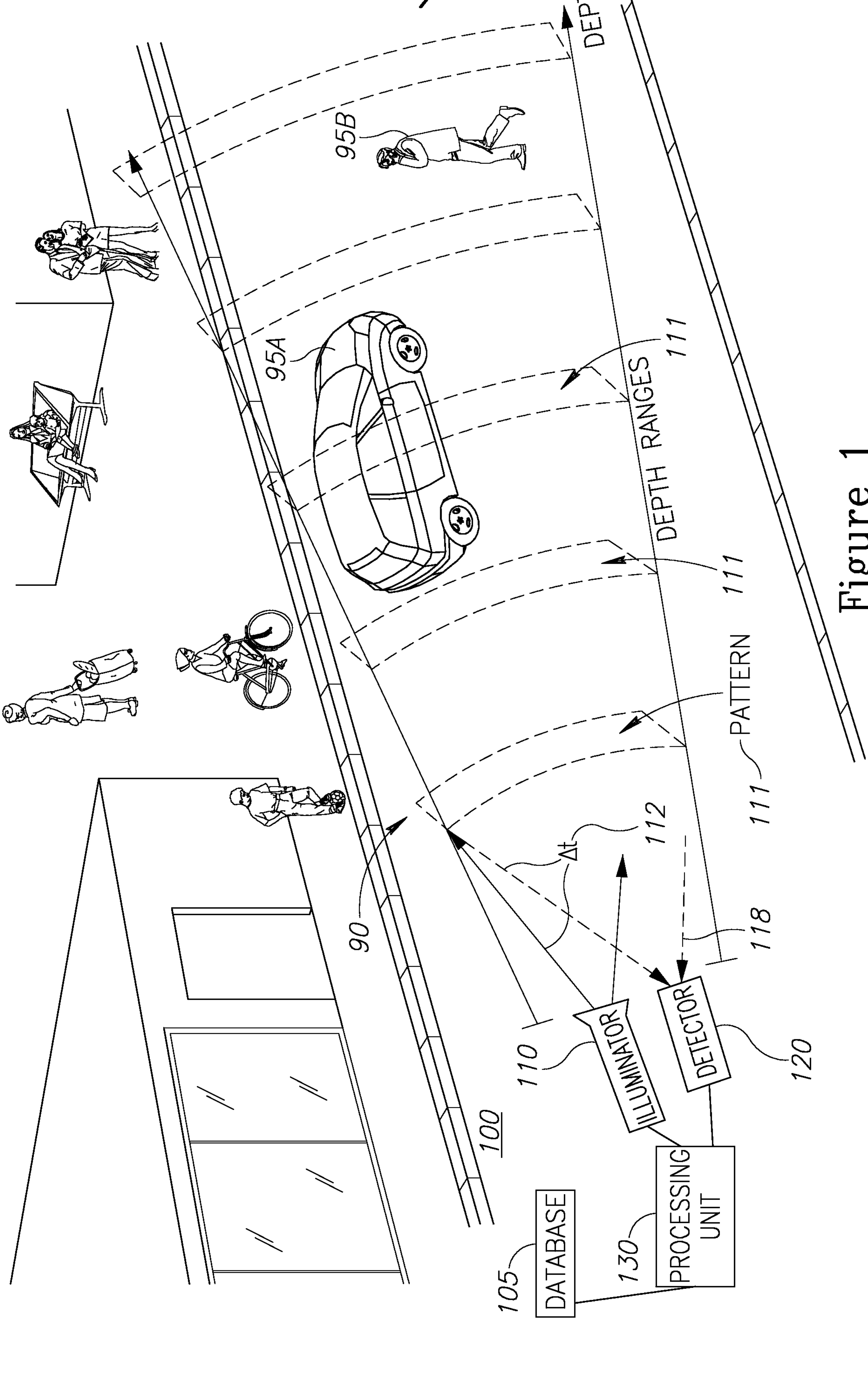

DEPTH
95B
95A
DEPTH RANGES
111
111
111
PATTERN
Δt
112
118
90
110
ILLUMINATOR
DETECTOR
120
100
DATABASE
105
PROCESSING UNIT
130

Figure 1

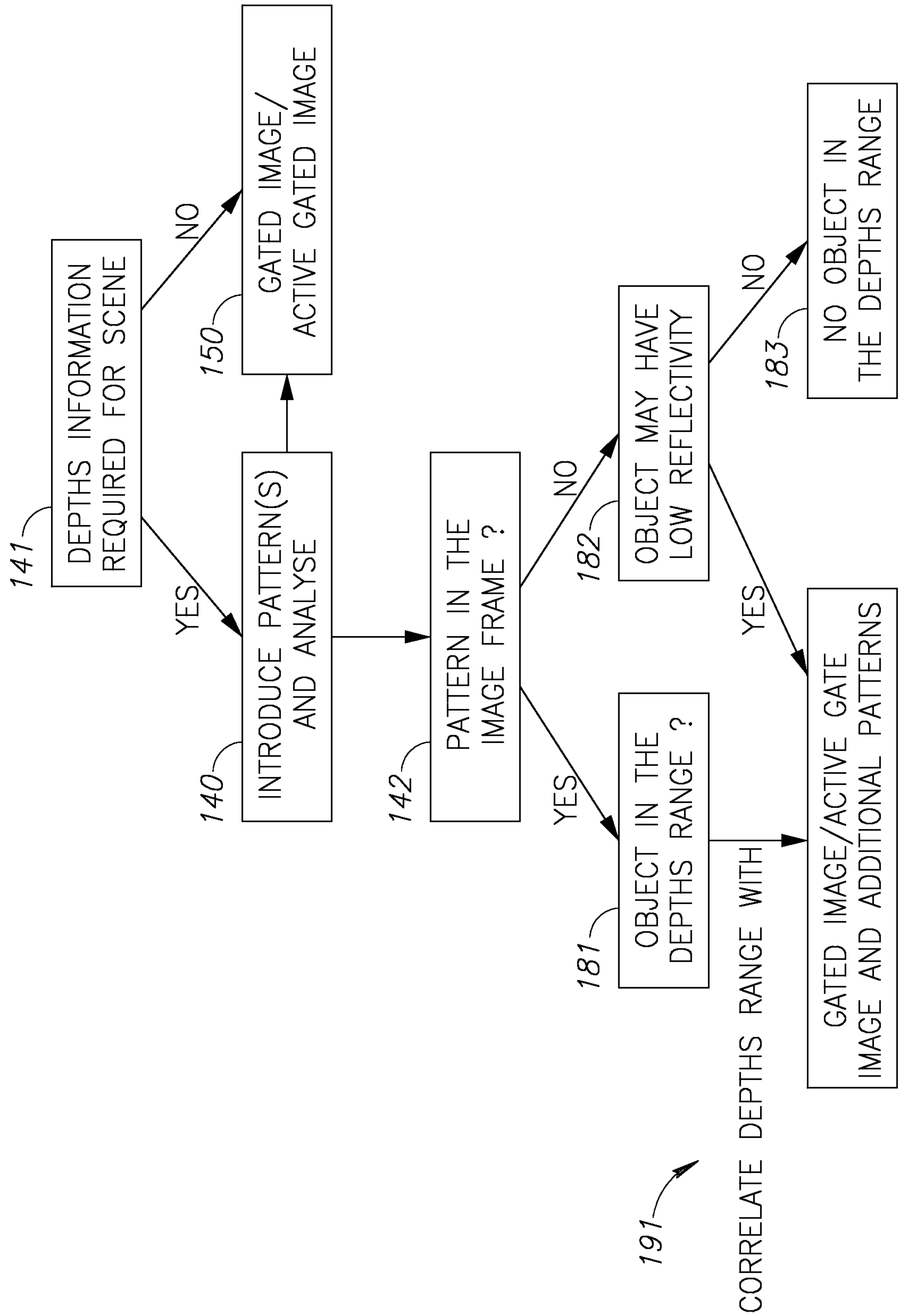

141
DEPTHS INFORMATION REQUIRED FOR SCENE
NO
YES
150
GATED IMAGE/ ACTIVE GATED IMAGE
140
INTRODUCE PATTERN(S) AND ANALYSE
142
PATTERN IN THE IMAGE FRAME ?
NO
YES
182
OBJECT MAY HAVE LOW REFLECTIVITY
NO
YES
183
NO OBJECT IN THE DEPTHS RANGE
181
OBJECT IN THE DEPTHS RANGE ?
GATED IMAGE/ACTIVE GATE IMAGE AND ADDITIONAL PATTERNS
191
CORRELATE DEPTHS RANGE WITH

Figure 2A

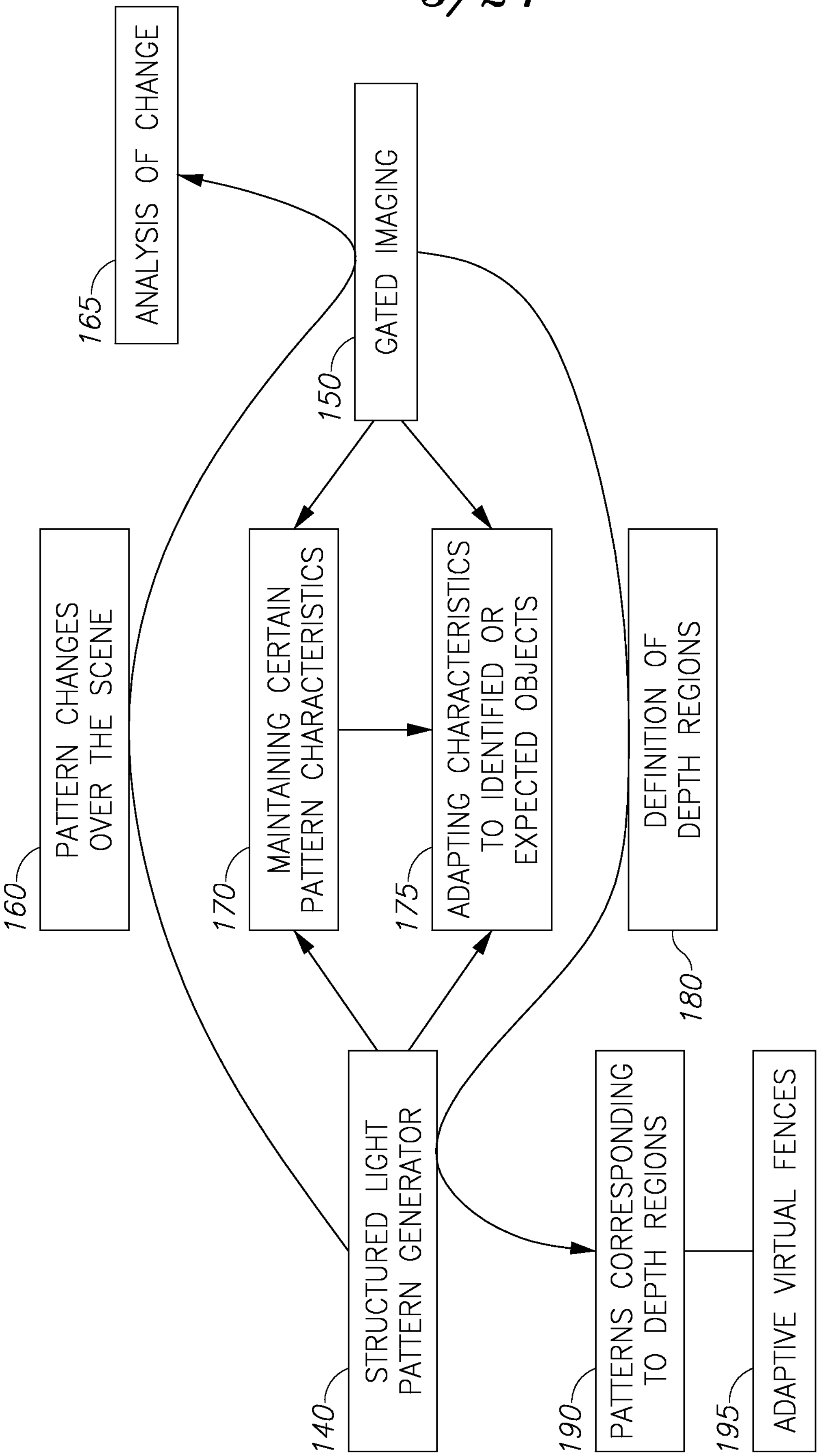

ANALYSIS OF CHANGE
165
GATED IMAGING
150
PATTERN CHANGES OVER THE SCENE
160
MAINTAINING CERTAIN PATTERN CHARACTERISTICS
170
ADAPTING CHARACTERISTICS TO IDENTIFIED OR EXPECTED OBJECTS
175
DEFINITION OF DEPTH REGIONS
180
STRUCTURED LIGHT PATTERN GENERATOR
140
PATTERNS CORRESPONDING TO DEPTH REGIONS
190
ADAPTIVE VIRTUAL FENCES
195

Figure 2B

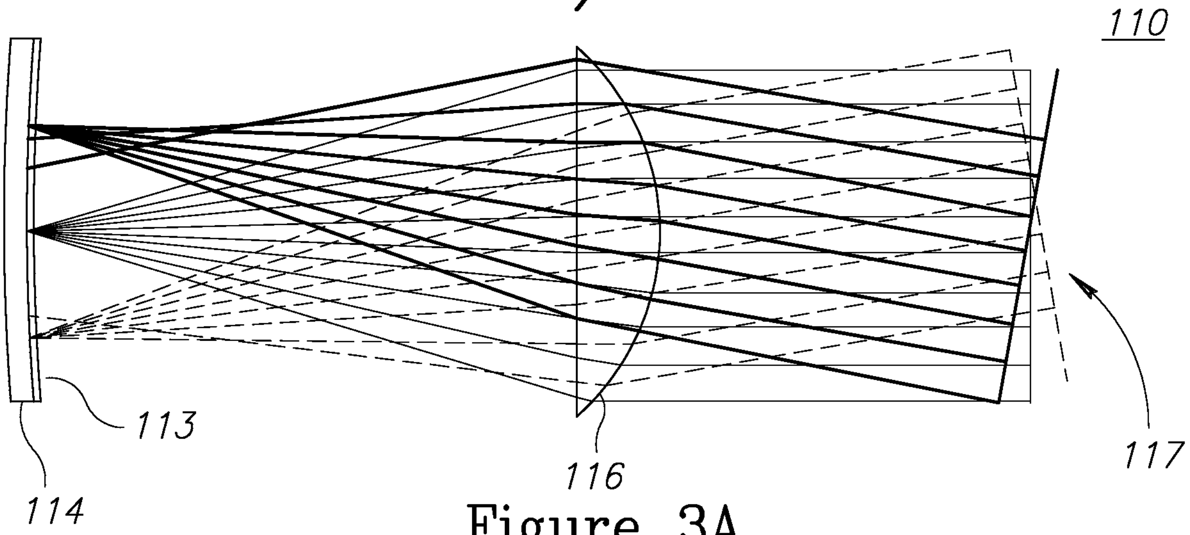


Figure 3A

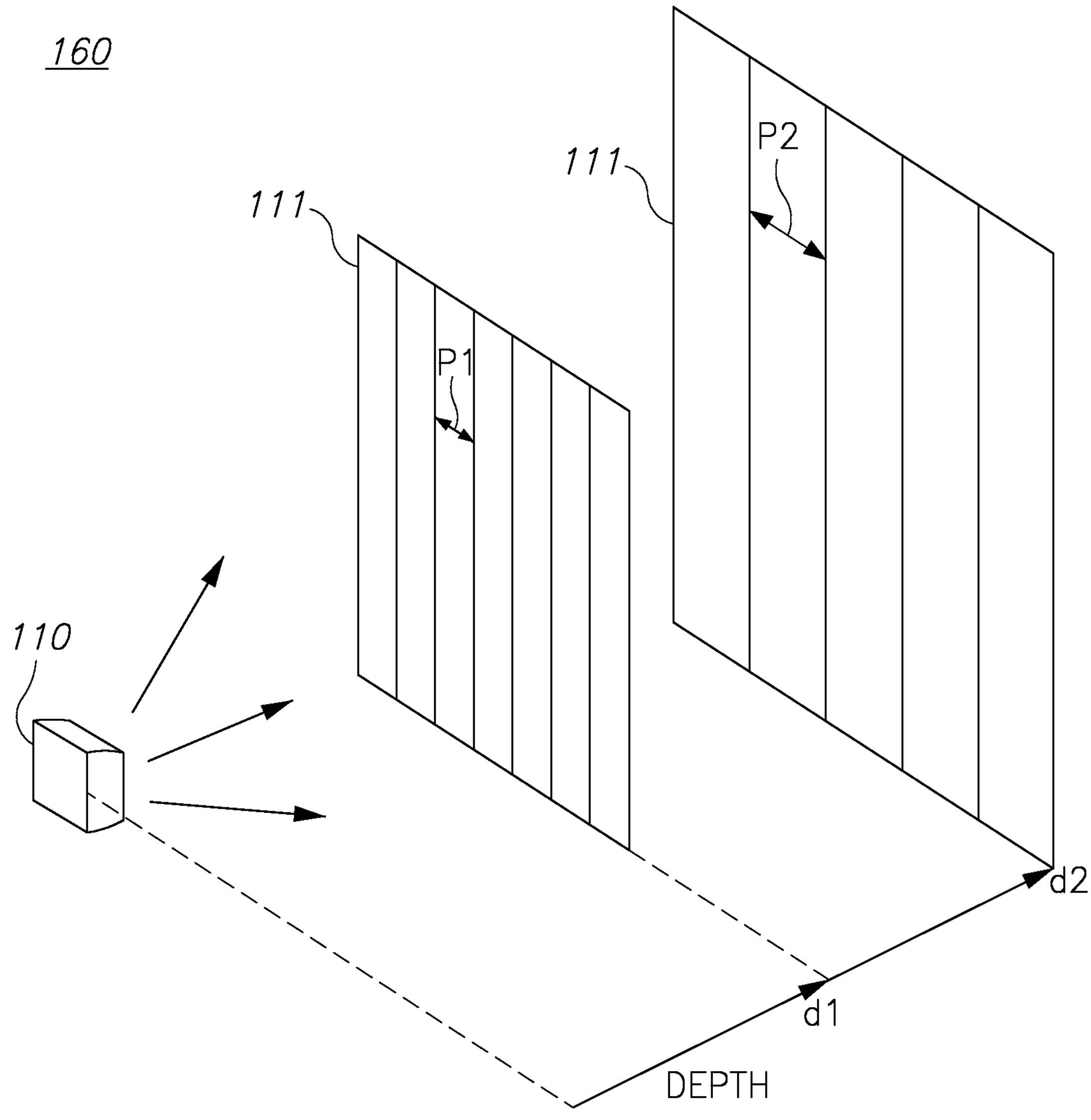


Figure 3B

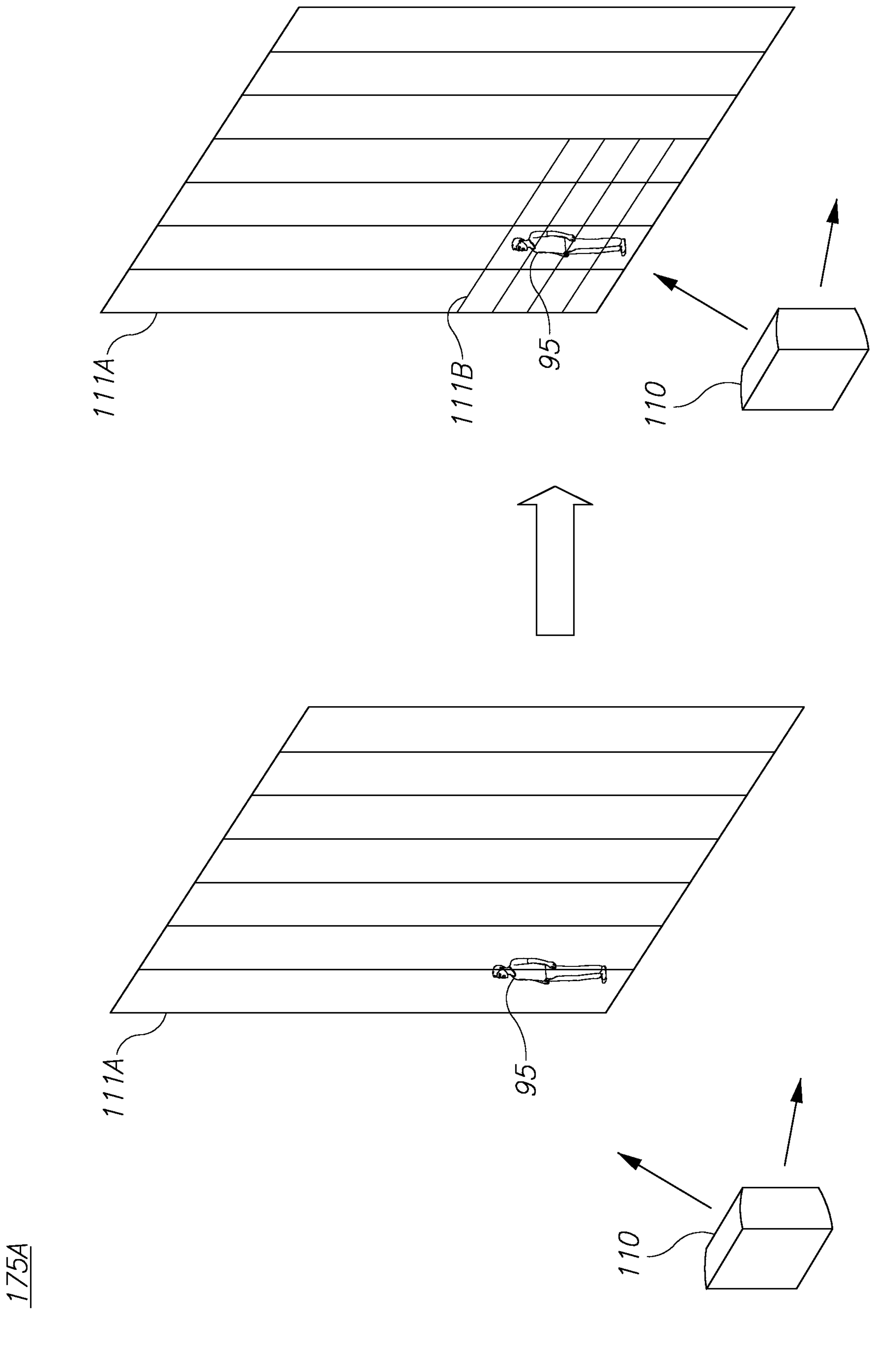


Figure 4A

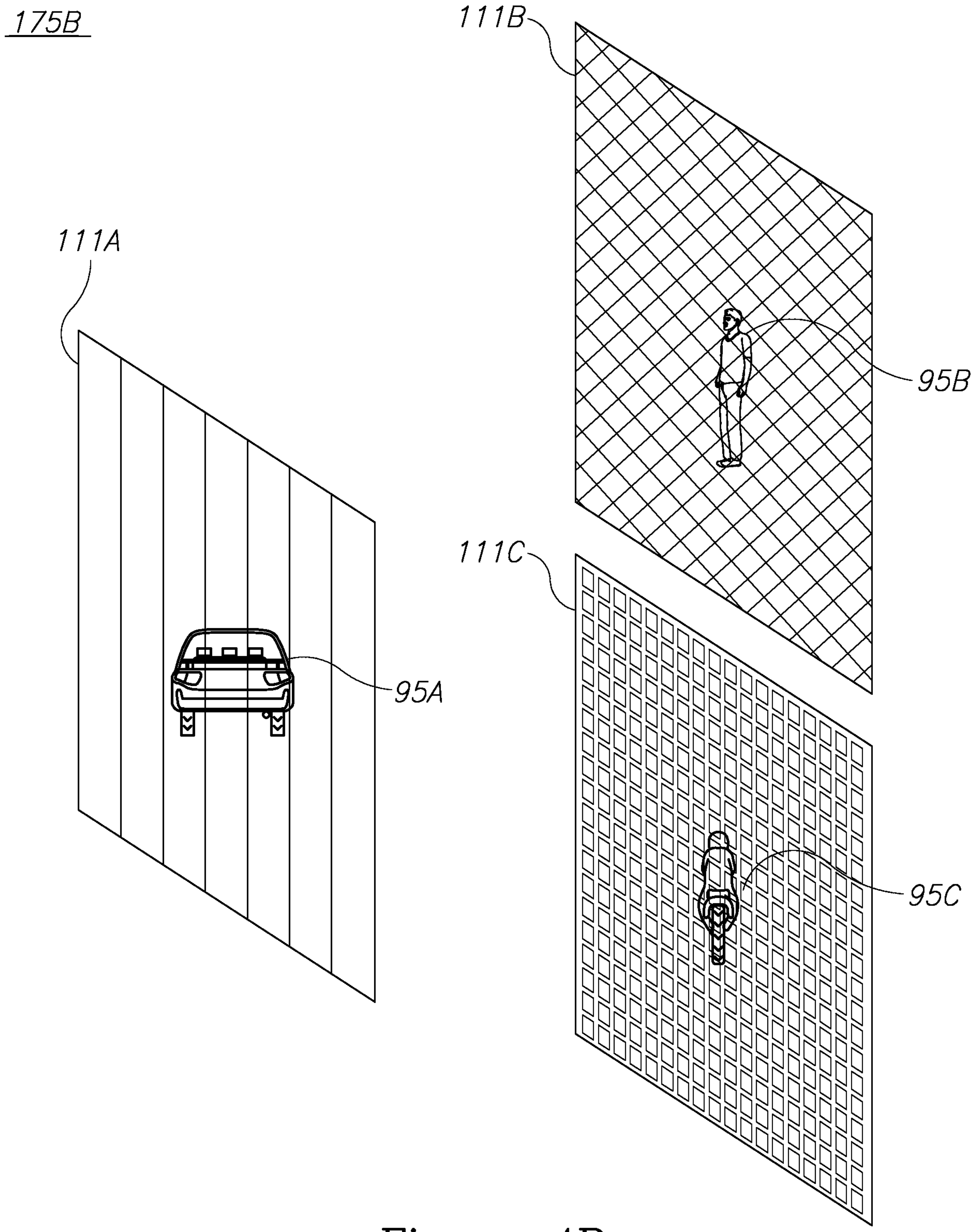


Figure 4B

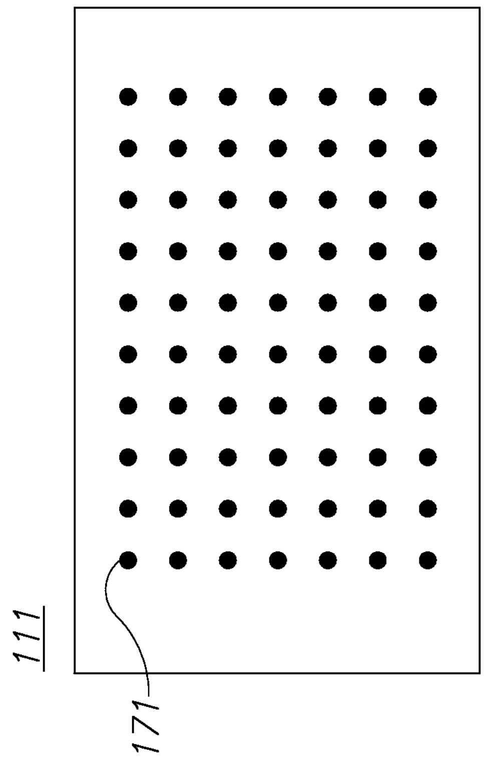


Figure 5A

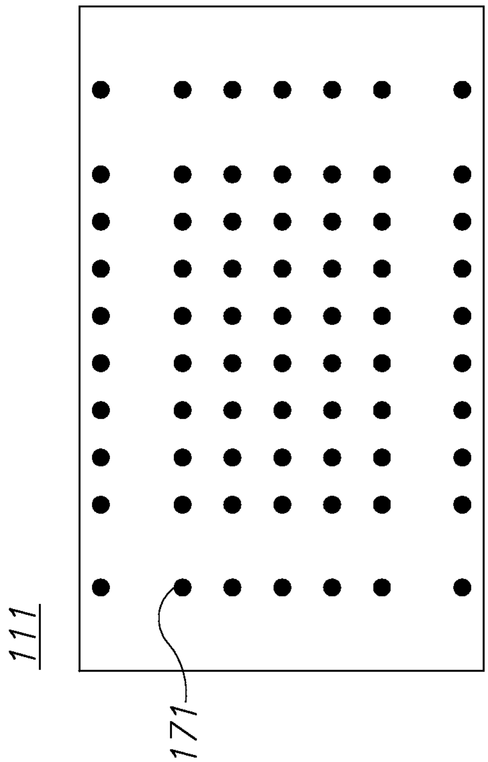


Figure 5B

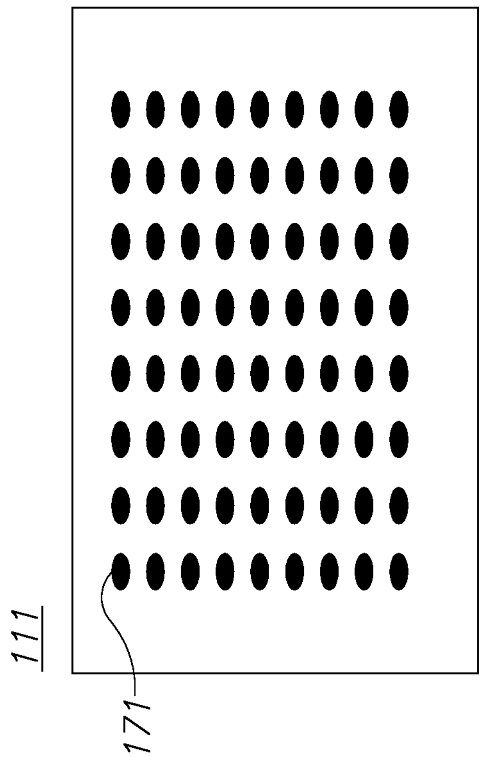


Figure 5C

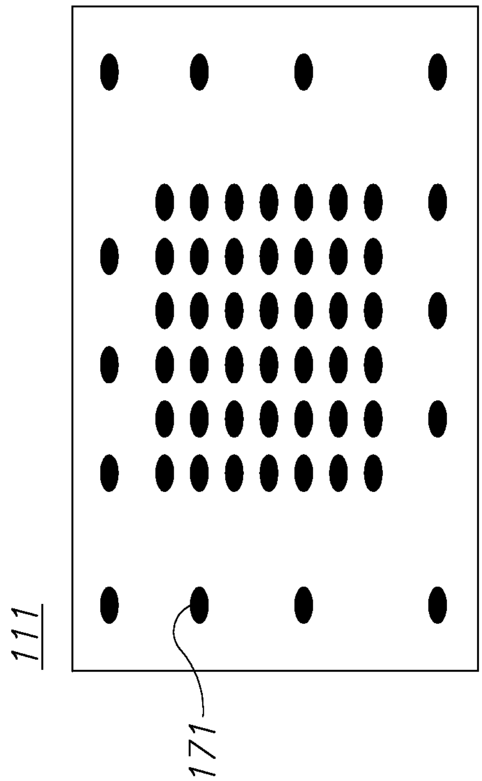


Figure 5D

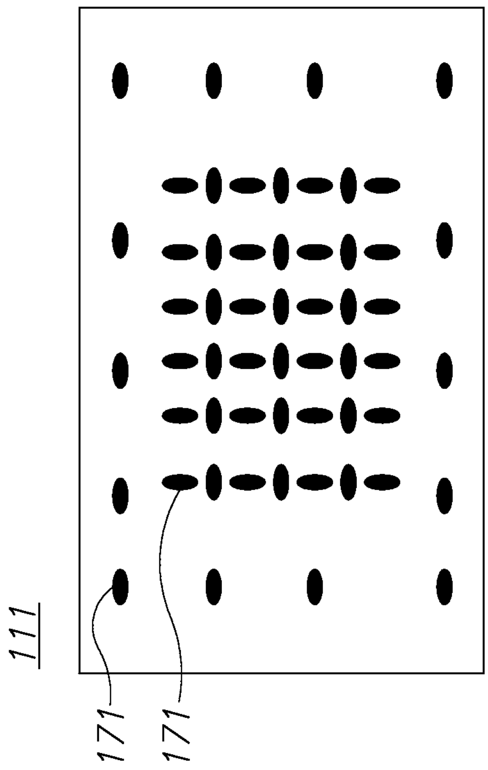


Figure 5E

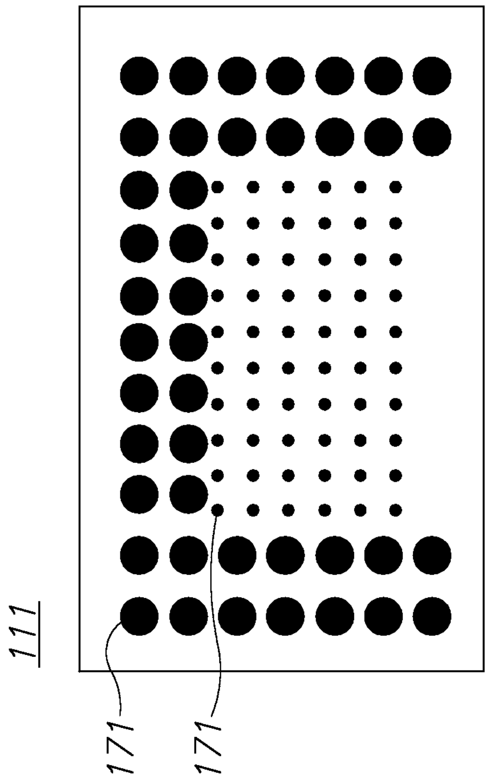


Figure 5F

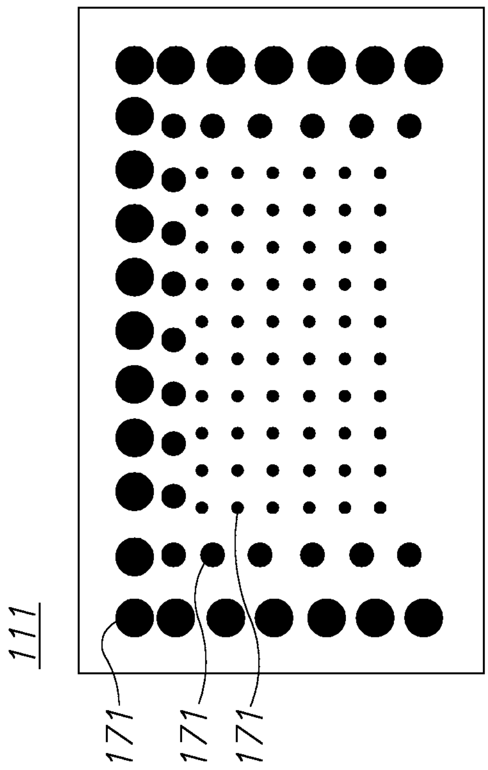


Figure 5G

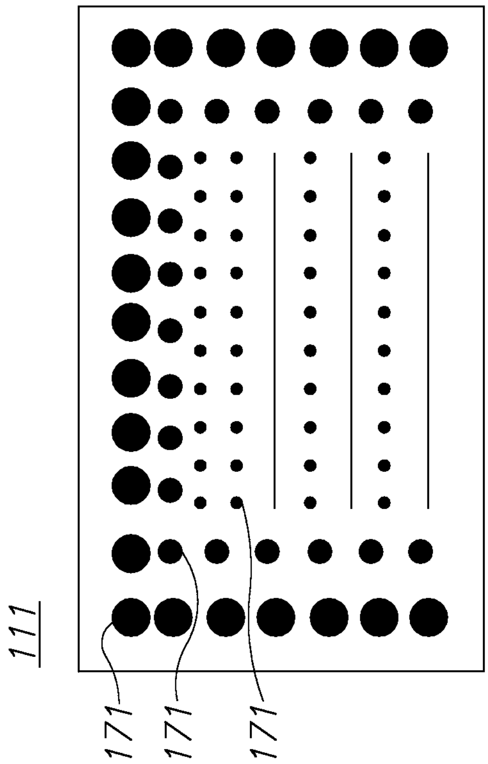
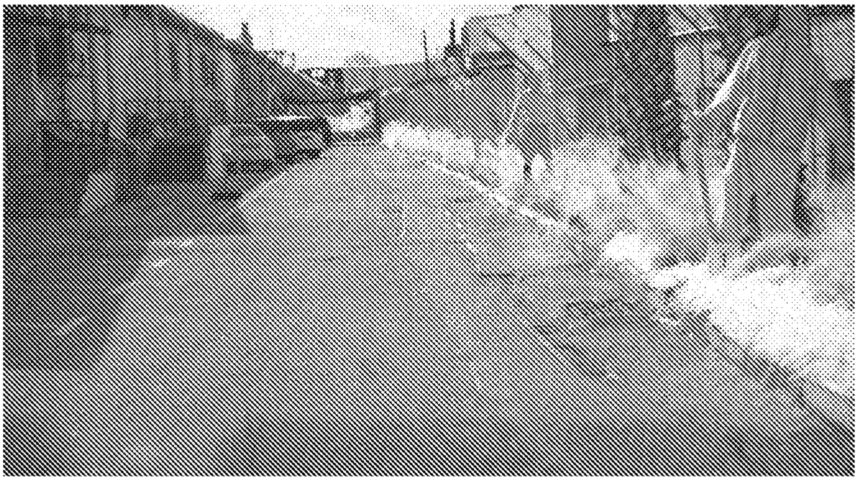
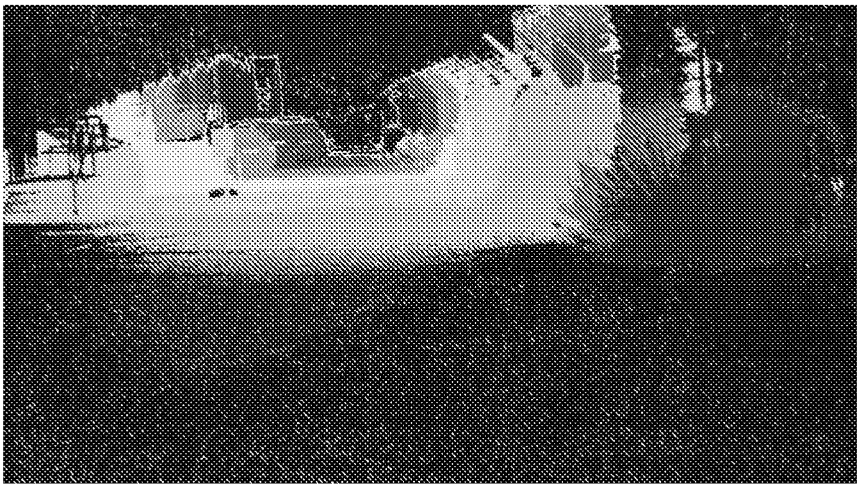


Figure 5H

125A



125B



125C

Figure 6

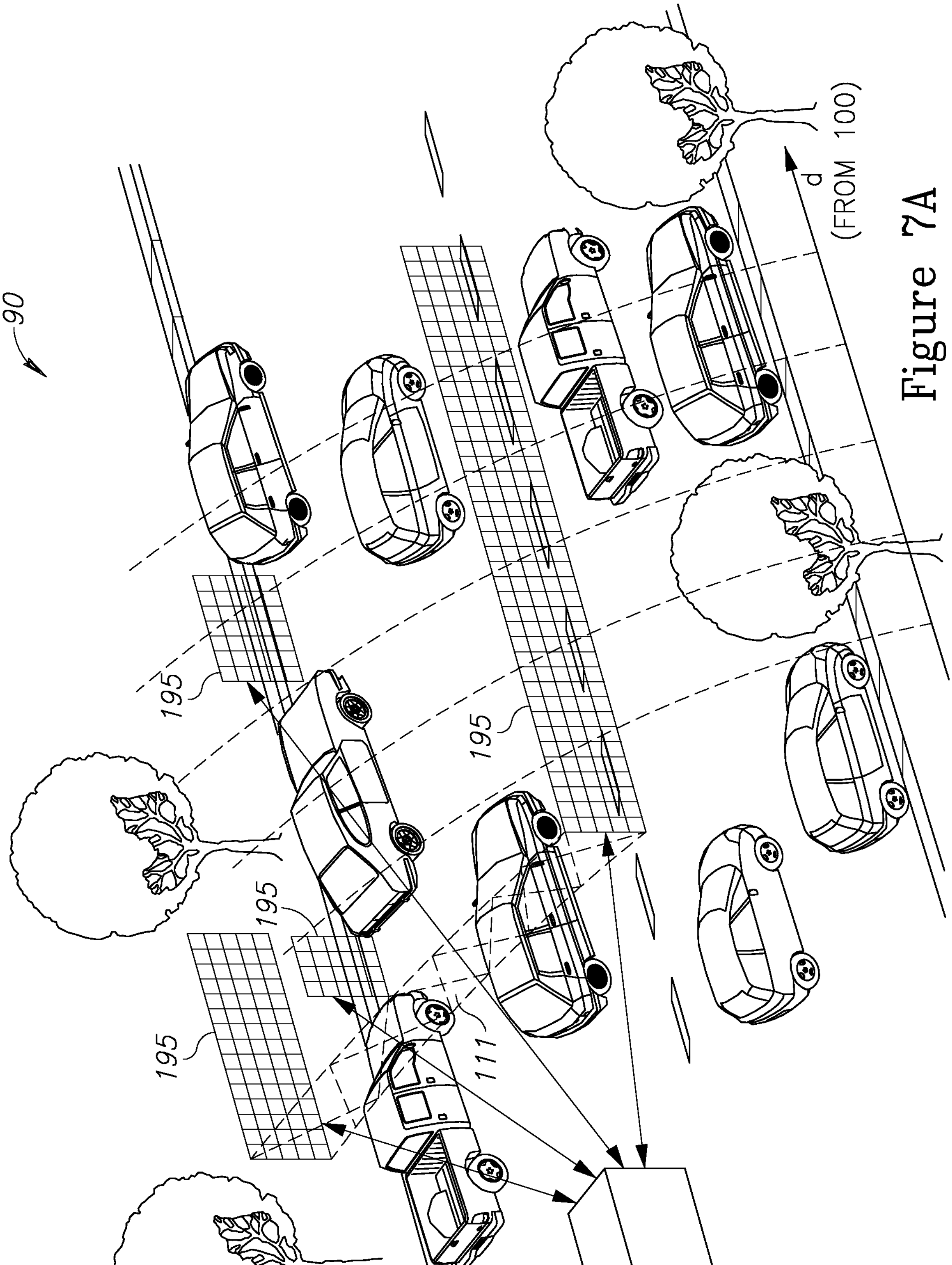


Figure 7A

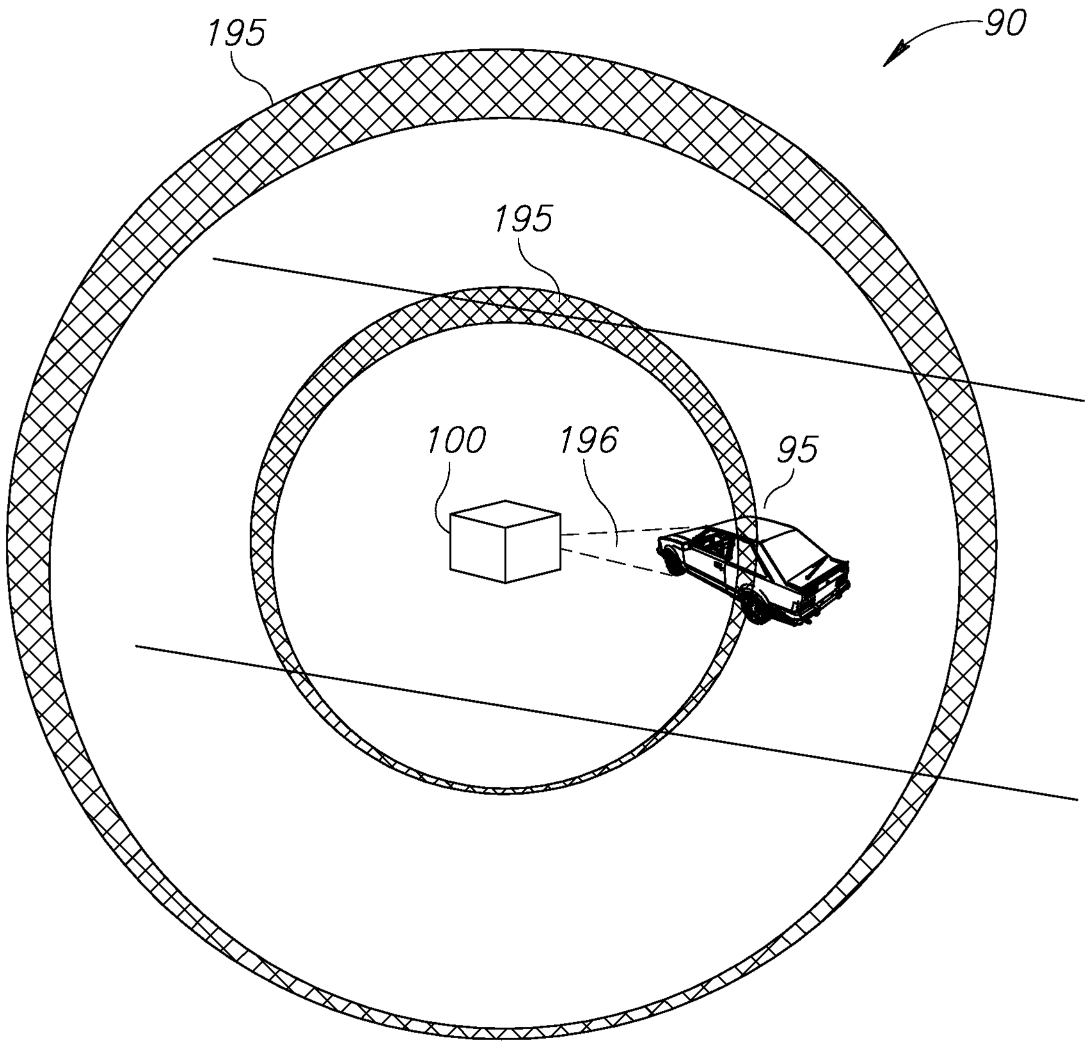


Figure 7B

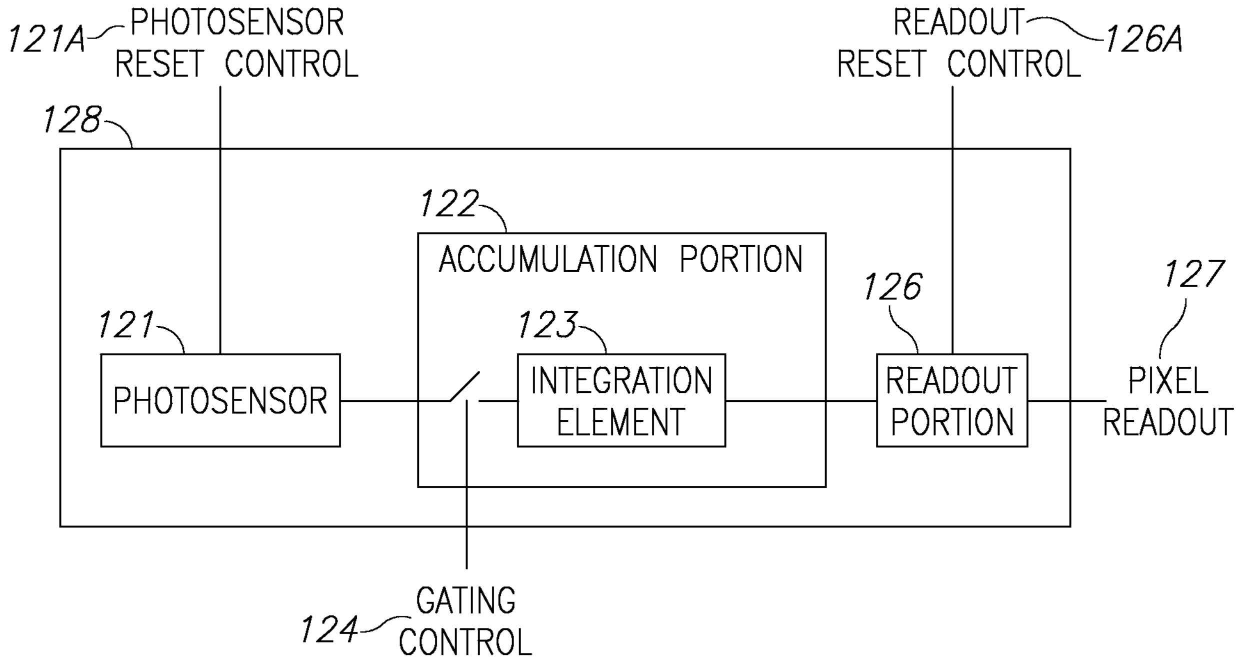


Figure 8A

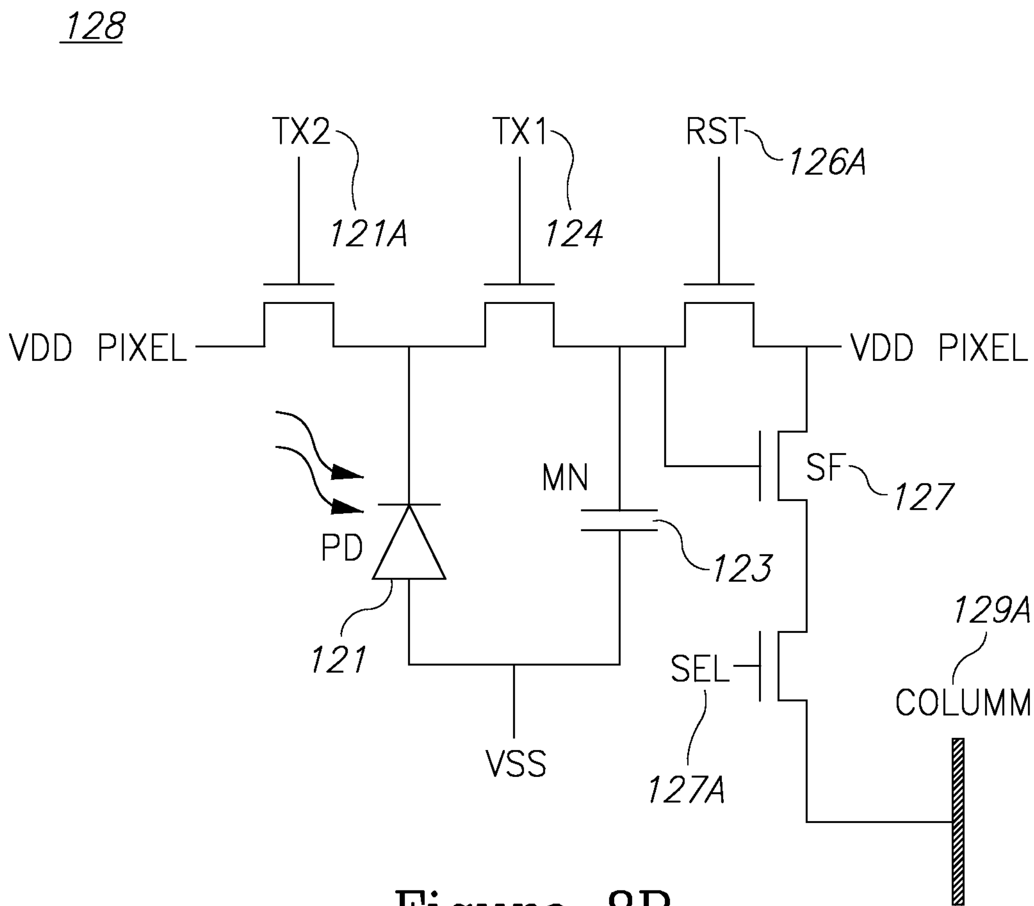


Figure 8B

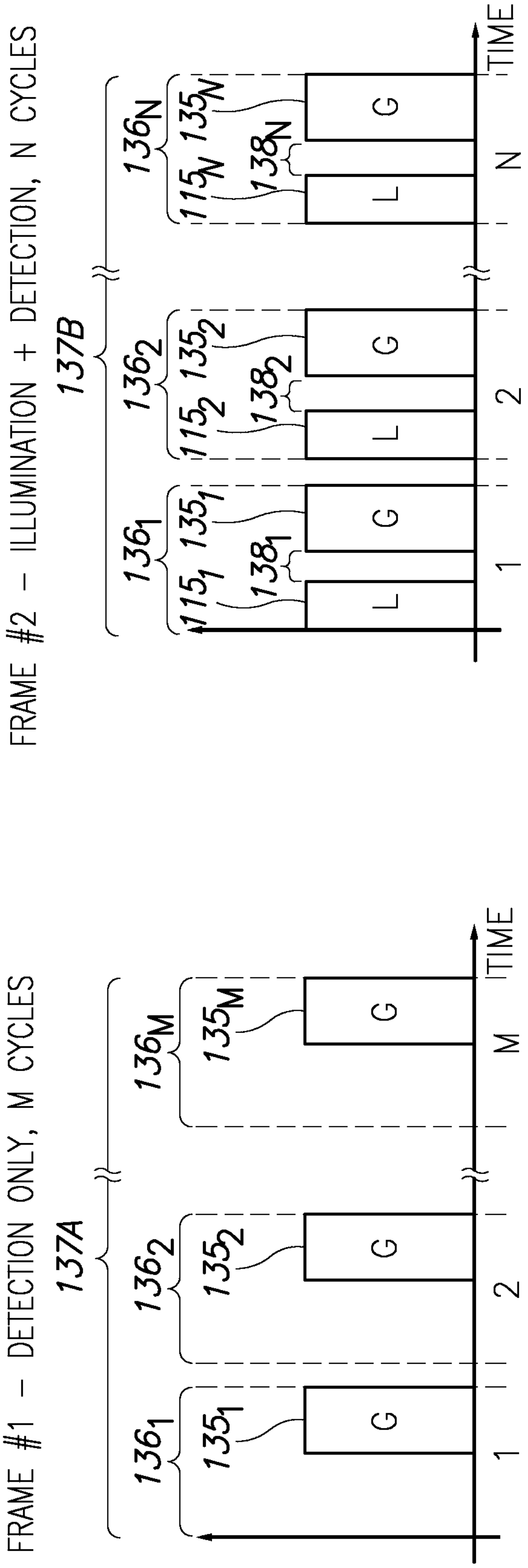


Figure 9A

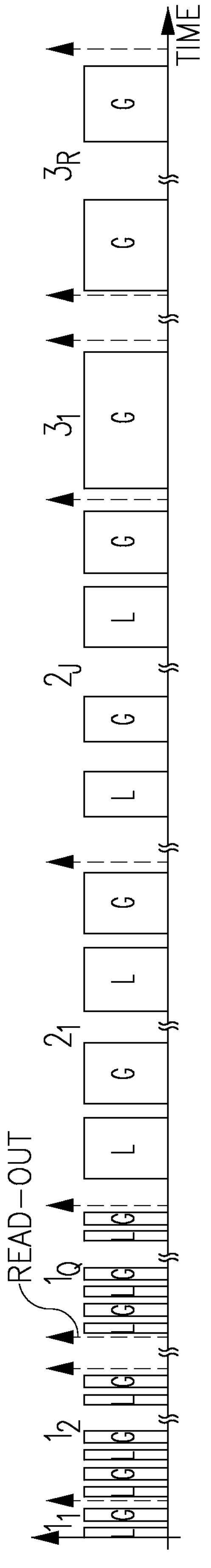


Figure 9B

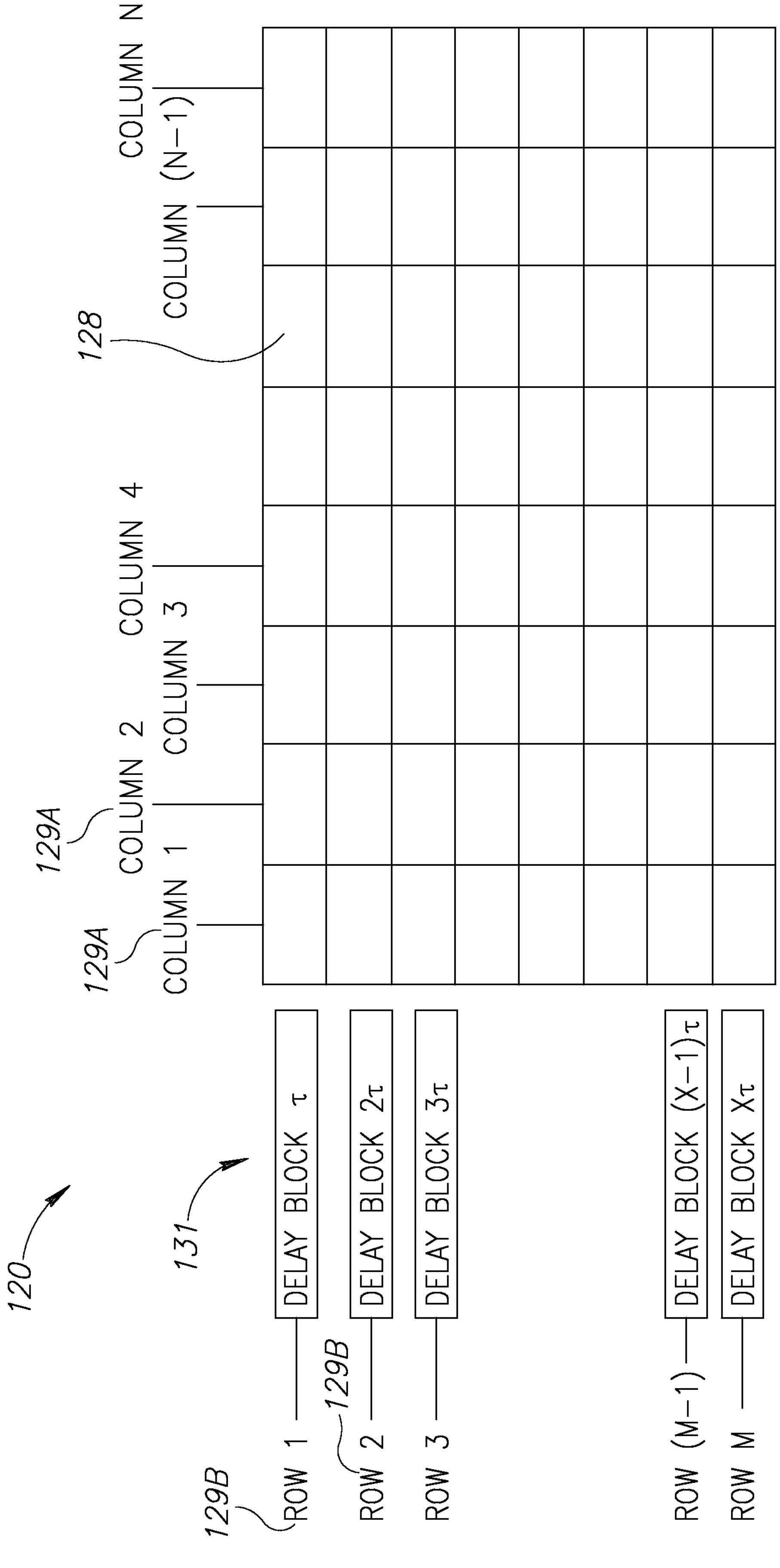

120
131
128
129A
129A
129B
129B
COLUMN 1
COLUMN 2
COLUMN 3
COLUMN 4
COLUMN (N−1)
COLUMN N
ROW 1
ROW 2
ROW 3
ROW (M−1)
ROW M
DELAY BLOCK τ
DELAY BLOCK 2τ
DELAY BLOCK 3τ
DELAY BLOCK (X−1)τ
DELAY BLOCK Xτ

Figure 10A

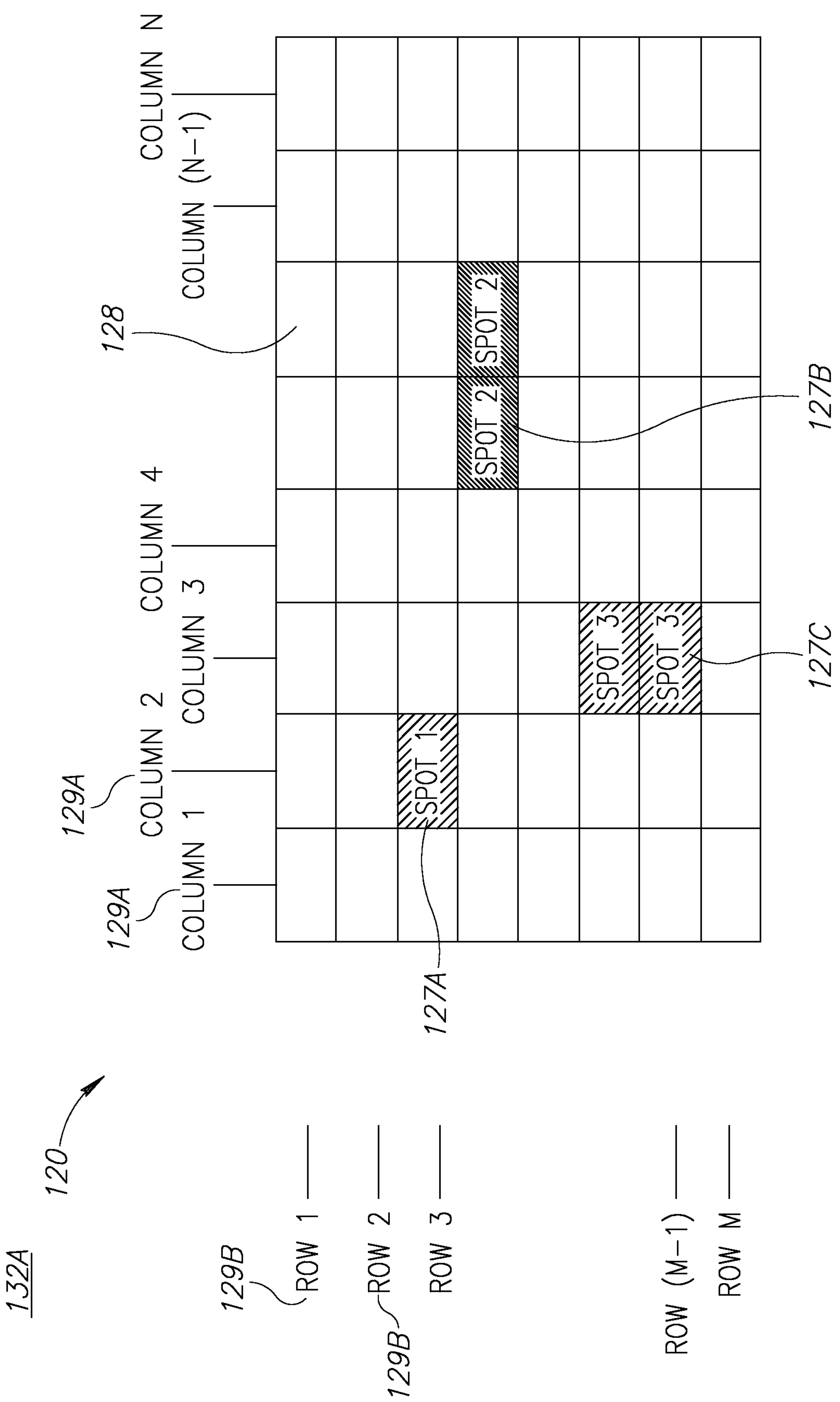

132A
120
129A
129A
COLUMN 1
COLUMN 2
COLUMN 3
COLUMN 4
COLUMN (N−1)
COLUMN N
128
SPOT 1
SPOT 2
SPOT 2
SPOT 3
SPOT 3
127A
127B
127C
129B
129B
ROW 1
ROW 2
ROW 3
ROW (M−1)
ROW M

Figure 10B

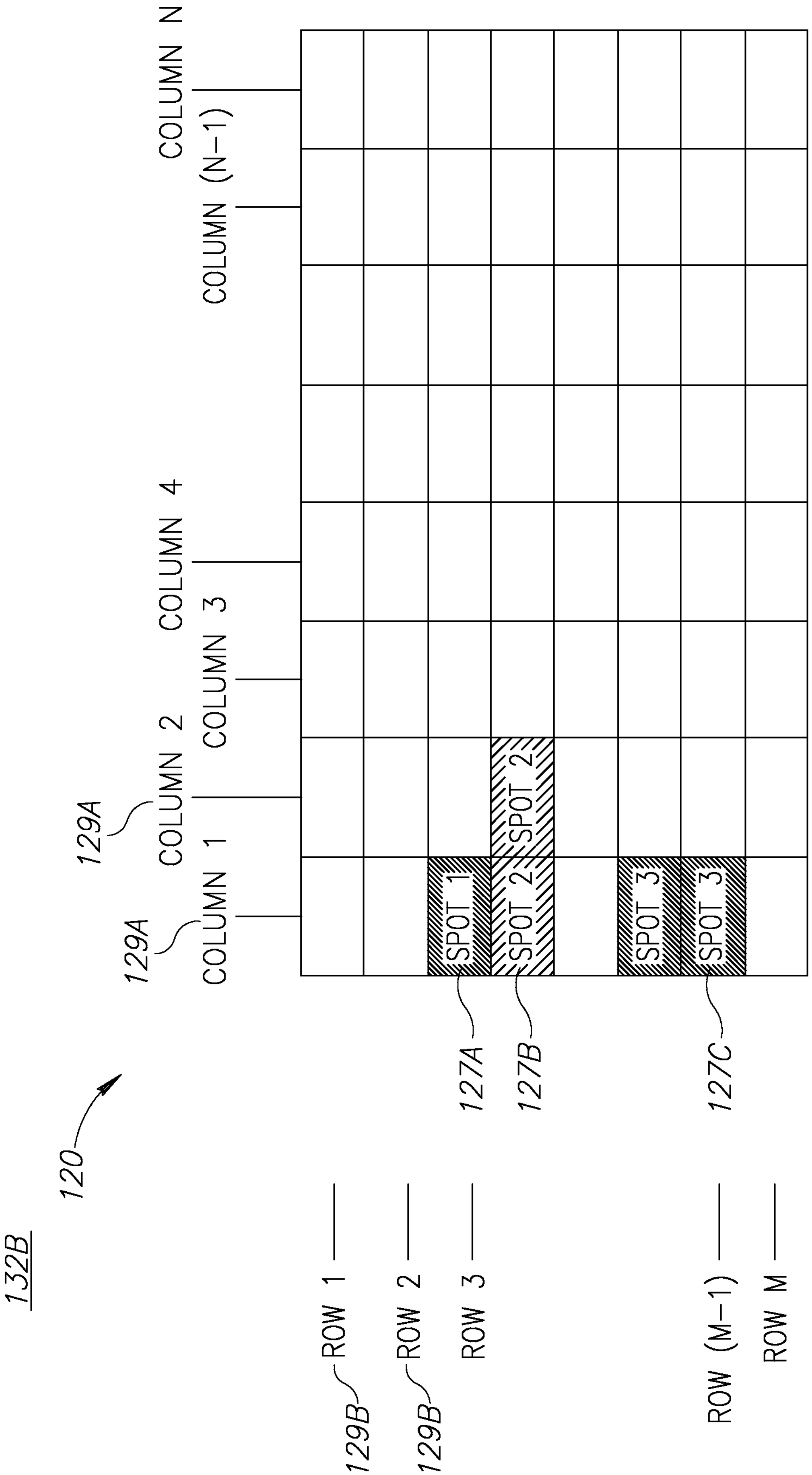

132B
120
129A
COLUMN 1
COLUMN 2
COLUMN 3
COLUMN 4
COLUMN (N−1)
COLUMN N
SPOT 1
SPOT 2
SPOT 3
127A
127B
127C
129B
ROW 1
ROW 2
ROW 3
ROW (M−1)
ROW M

Figure 10C

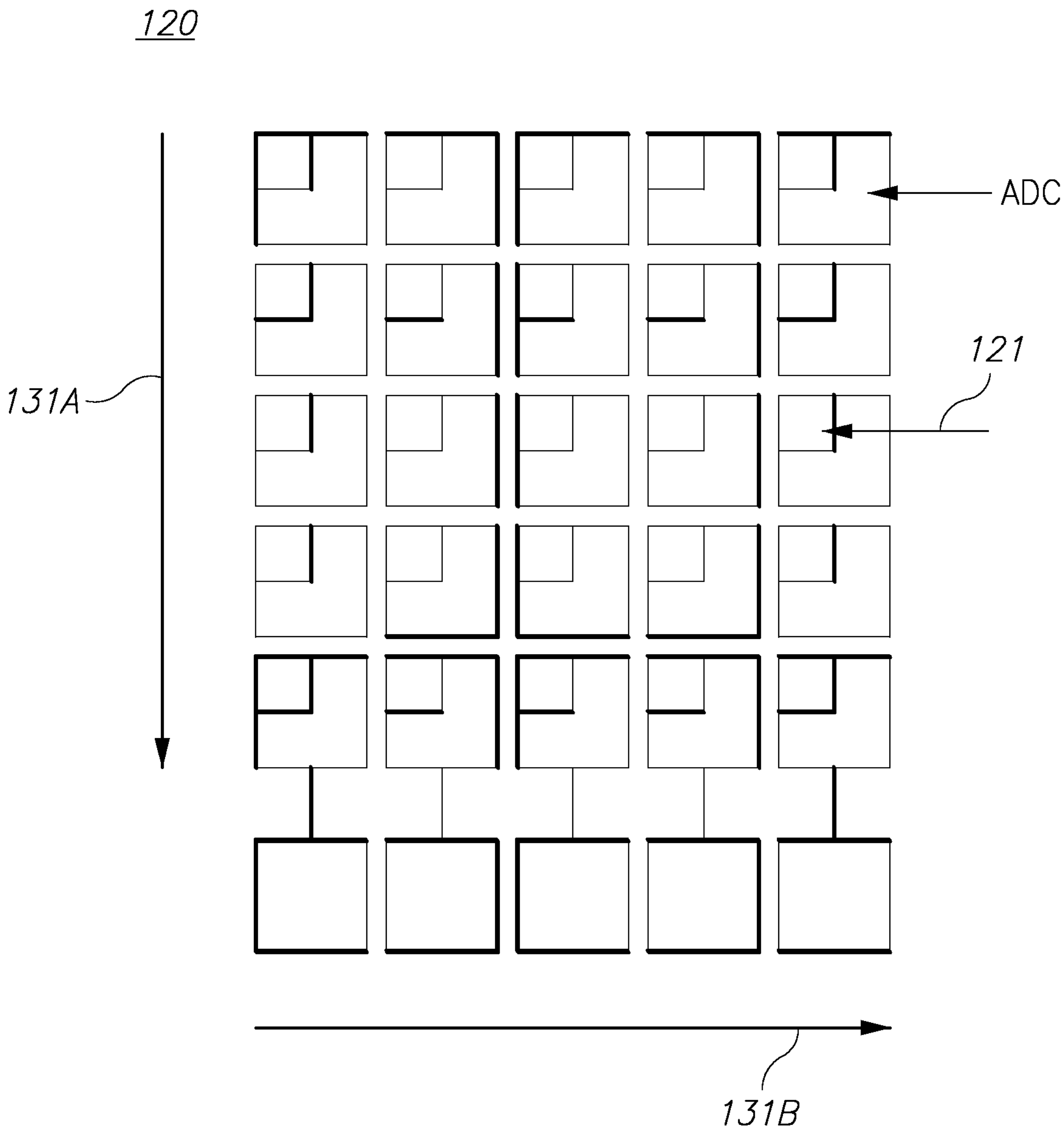


Figure 10D

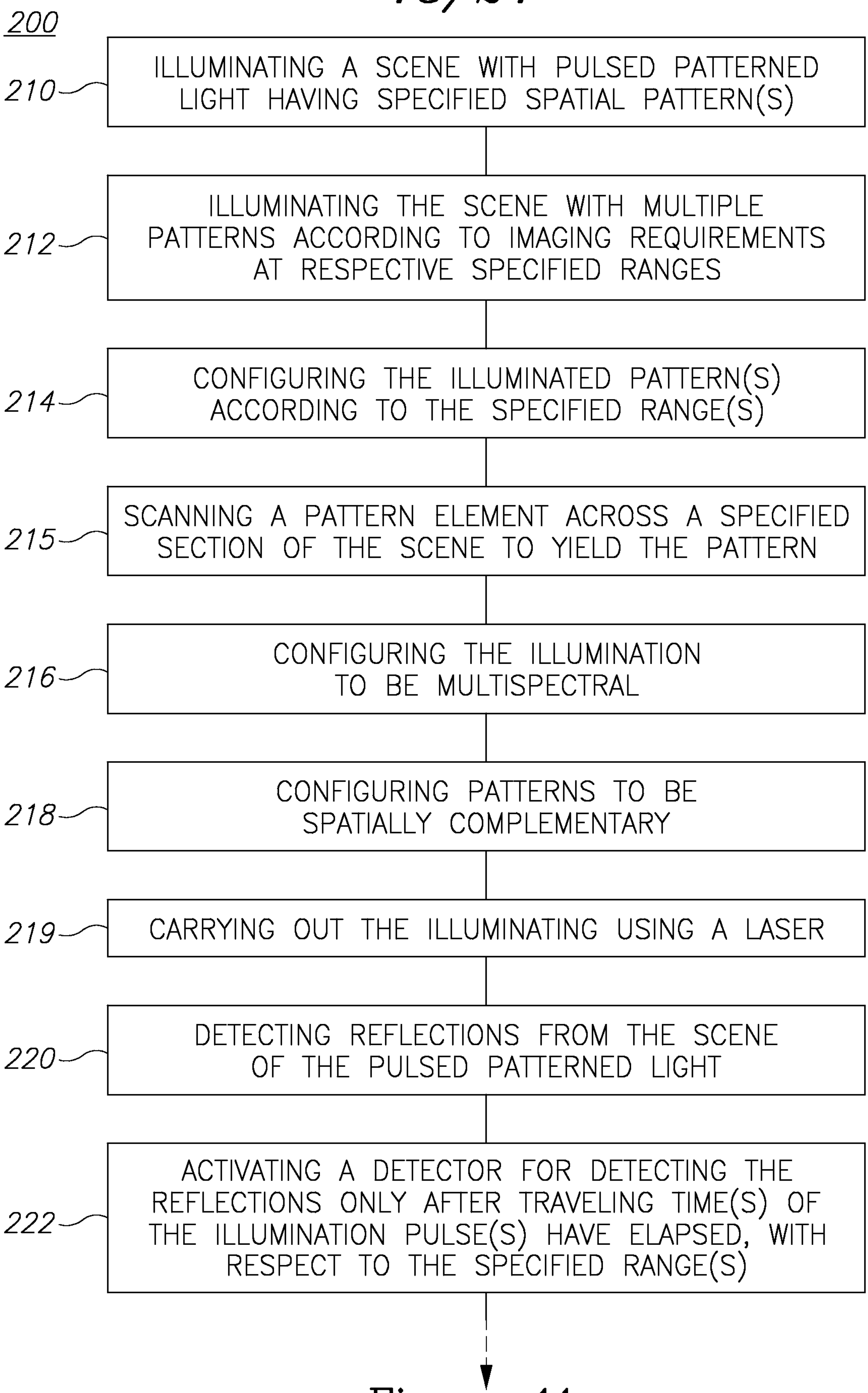

200
210
ILLUMINATING A SCENE WITH PULSED PATTERNED LIGHT HAVING SPECIFIED SPATIAL PATTERN(S)
212
ILLUMINATING THE SCENE WITH MULTIPLE PATTERNS ACCORDING TO IMAGING REQUIREMENTS AT RESPECTIVE SPECIFIED RANGES
214
CONFIGURING THE ILLUMINATED PATTERN(S) ACCORDING TO THE SPECIFIED RANGE(S)
215
SCANNING A PATTERN ELEMENT ACROSS A SPECIFIED SECTION OF THE SCENE TO YIELD THE PATTERN
216
CONFIGURING THE ILLUMINATION TO BE MULTISPECTRAL
218
CONFIGURING PATTERNS TO BE SPATIALLY COMPLEMENTARY
219
CARRYING OUT THE ILLUMINATING USING A LASER
220
DETECTING REFLECTIONS FROM THE SCENE OF THE PULSED PATTERNED LIGHT
222
ACTIVATING A DETECTOR FOR DETECTING THE REFLECTIONS ONLY AFTER TRAVELING TIME(S) OF THE ILLUMINATION PULSE(S) HAVE ELAPSED, WITH RESPECT TO THE SPECIFIED RANGE(S)

Figure 11

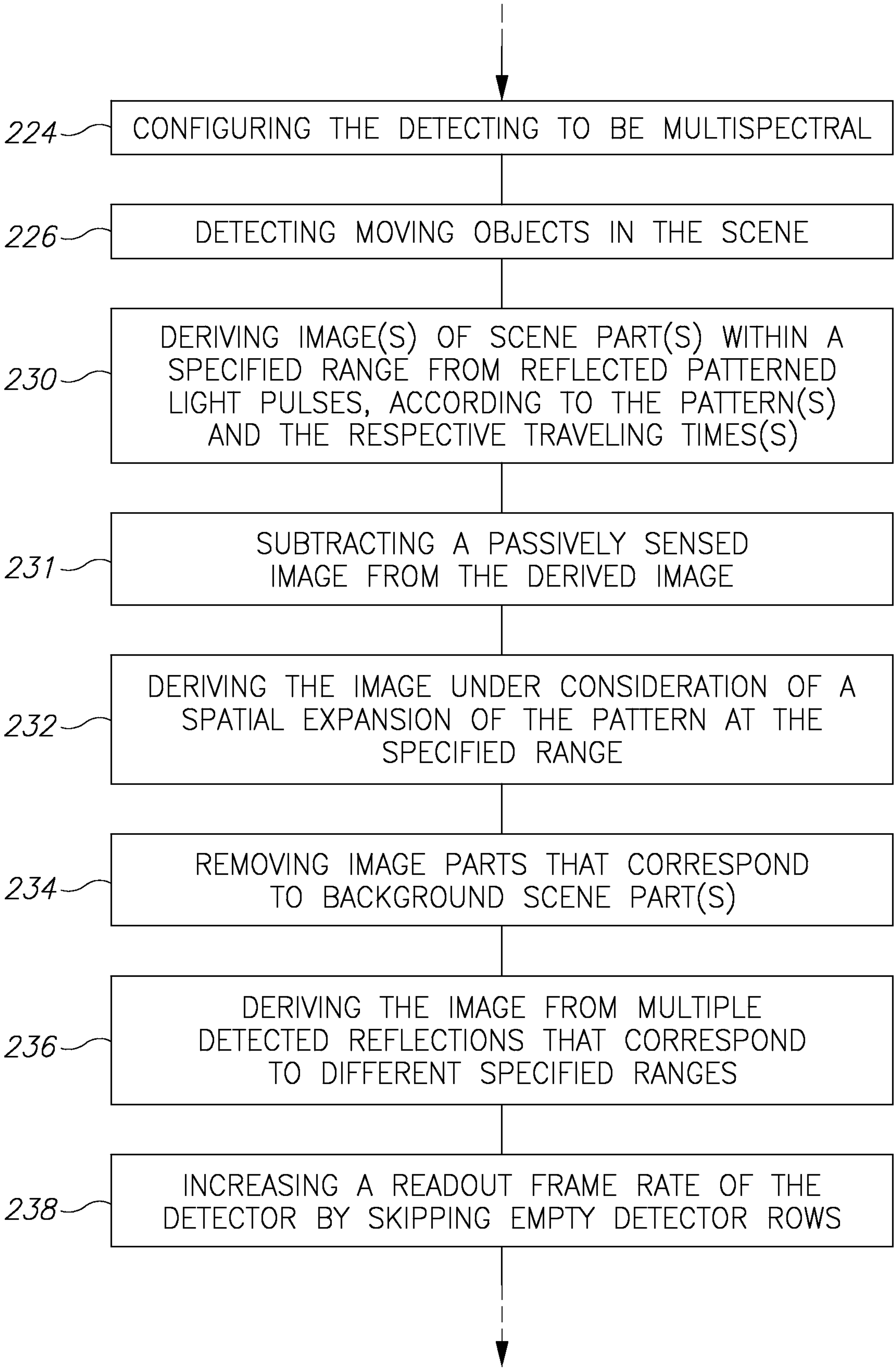


Figure 11 (cont. 1)

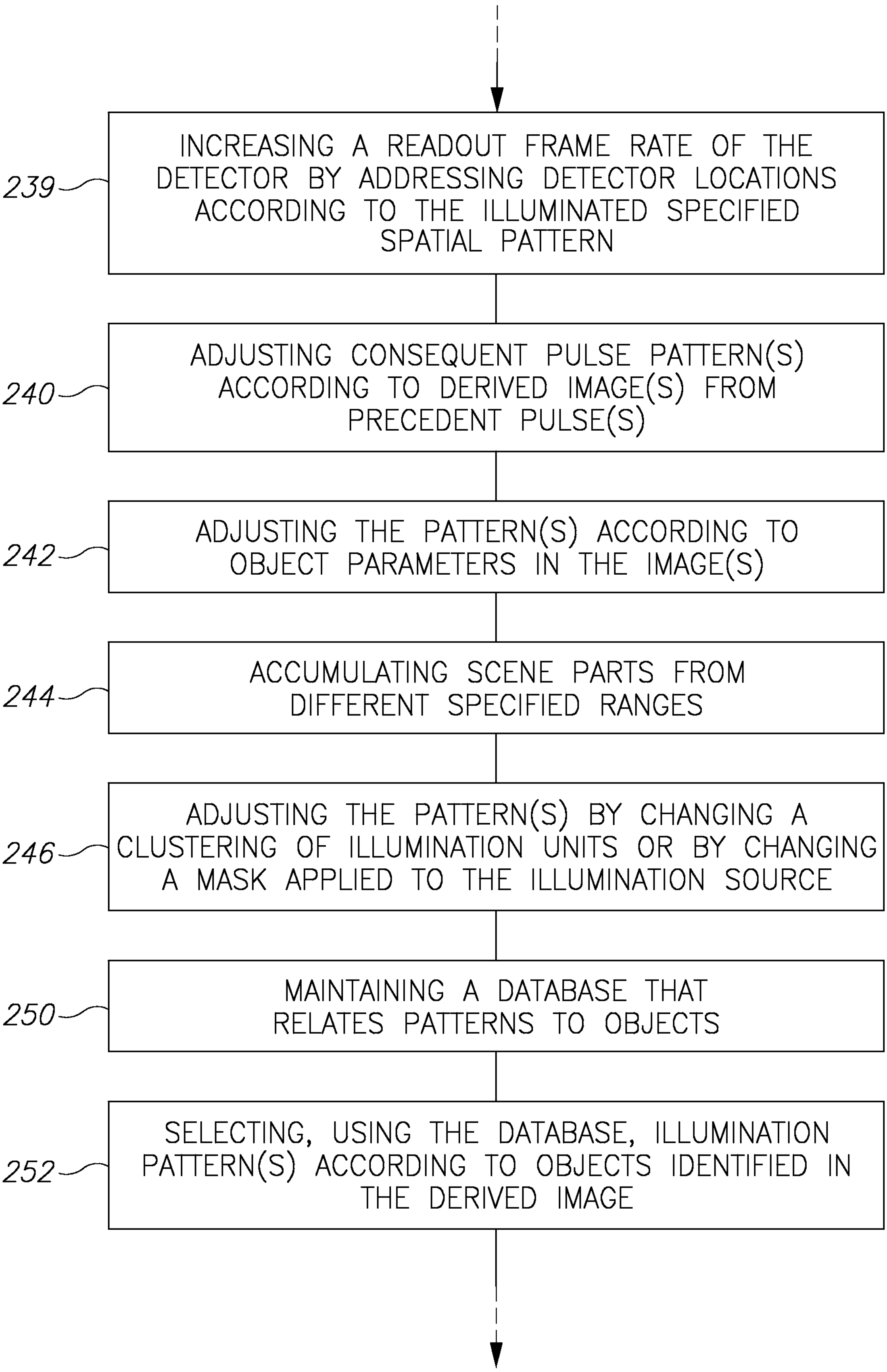


Figure 11 (cont. 2)

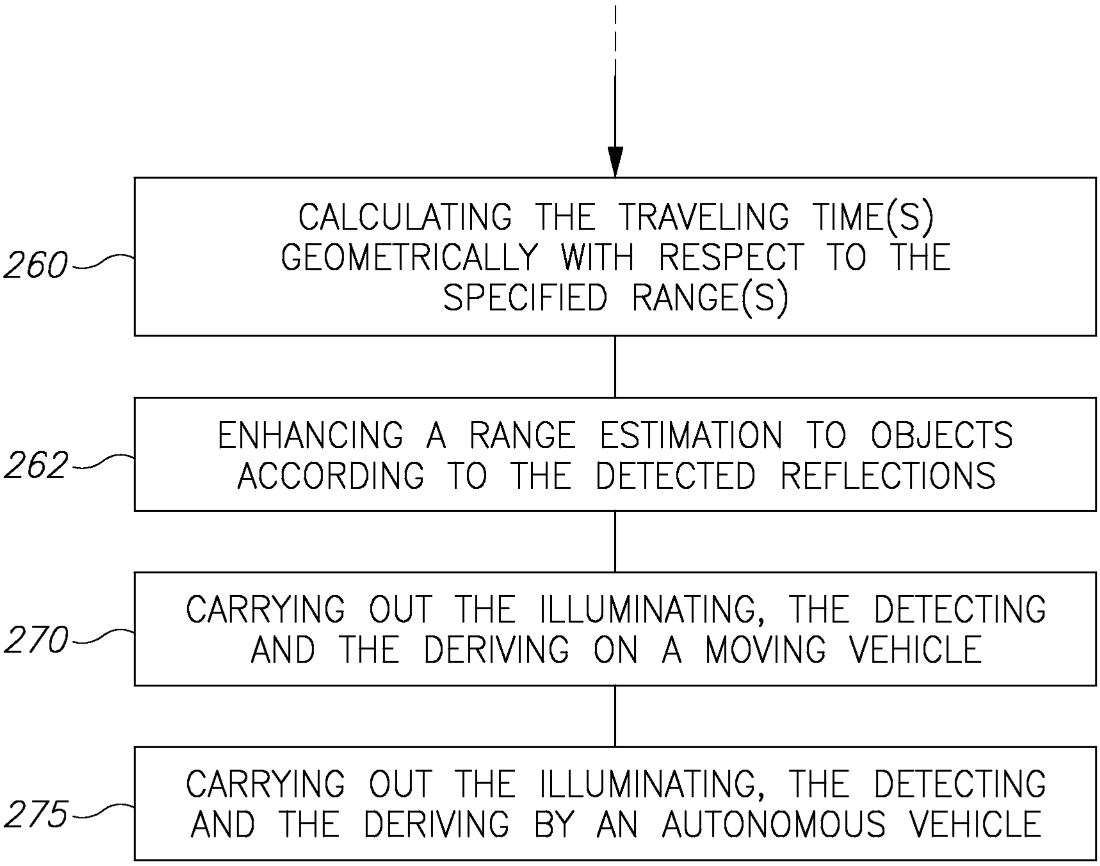


Figure 11 (cont. 3)

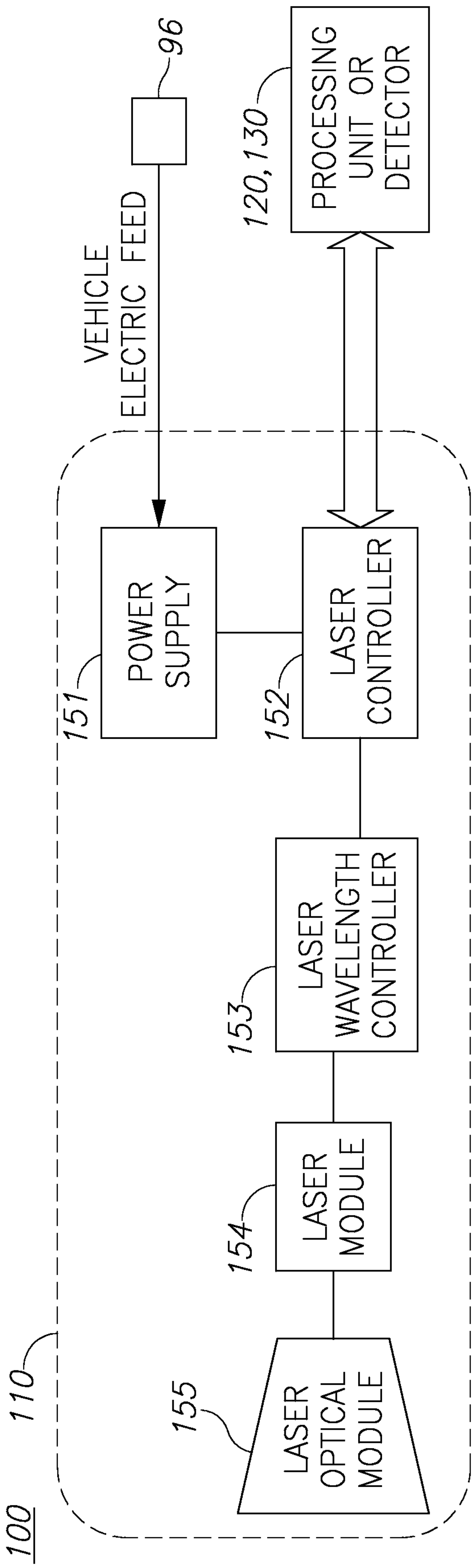


Figure 12A

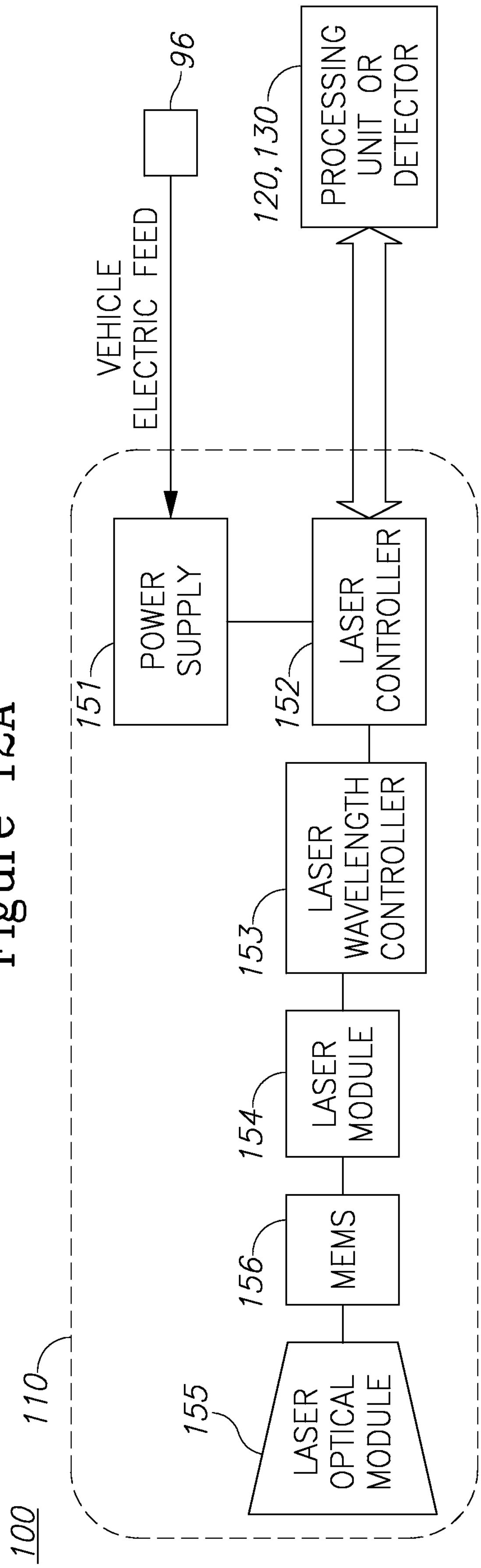


Figure 12B

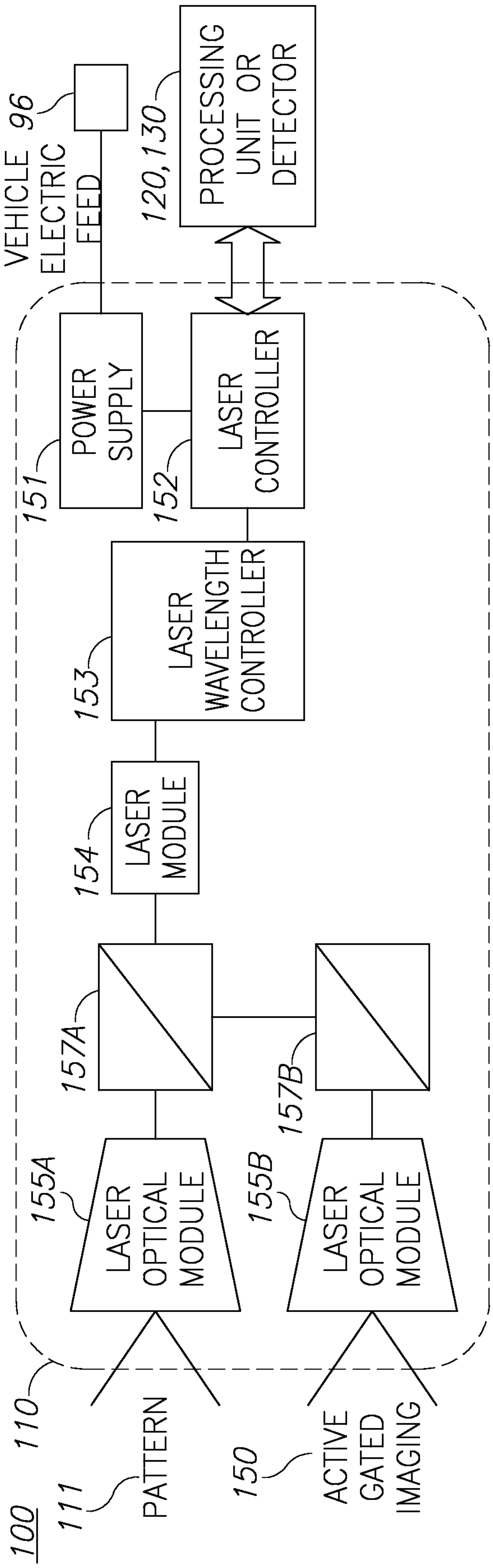


Figure 12C

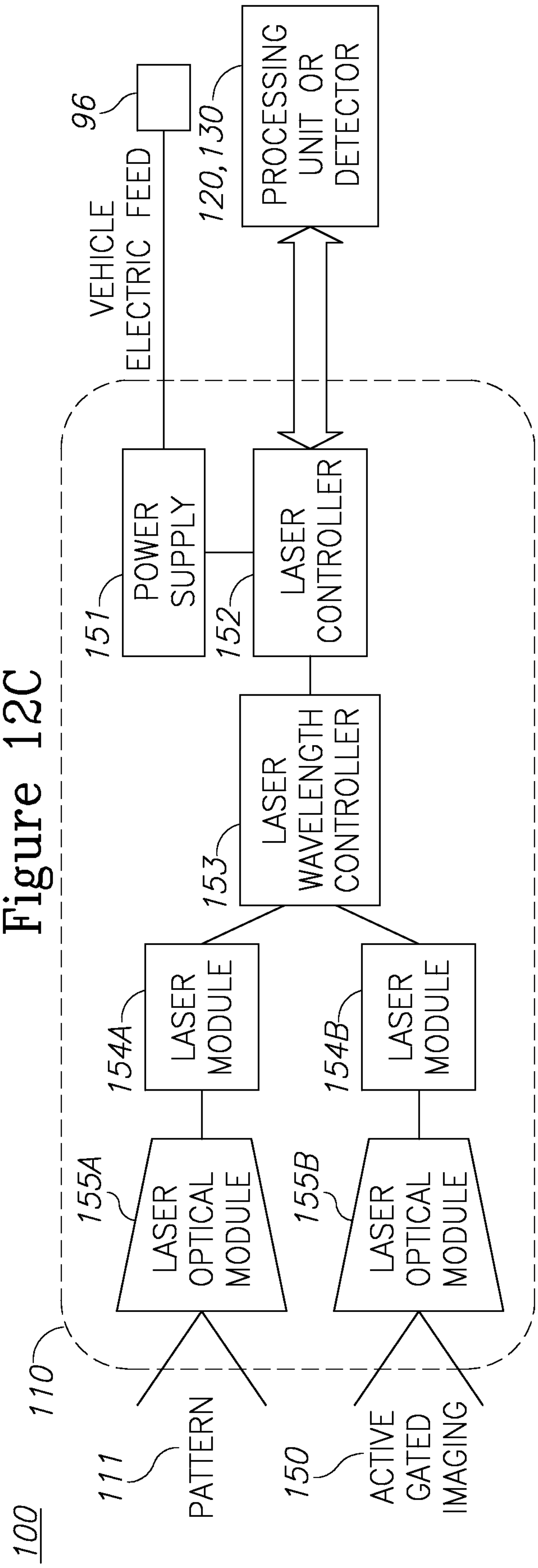


Figure 12D

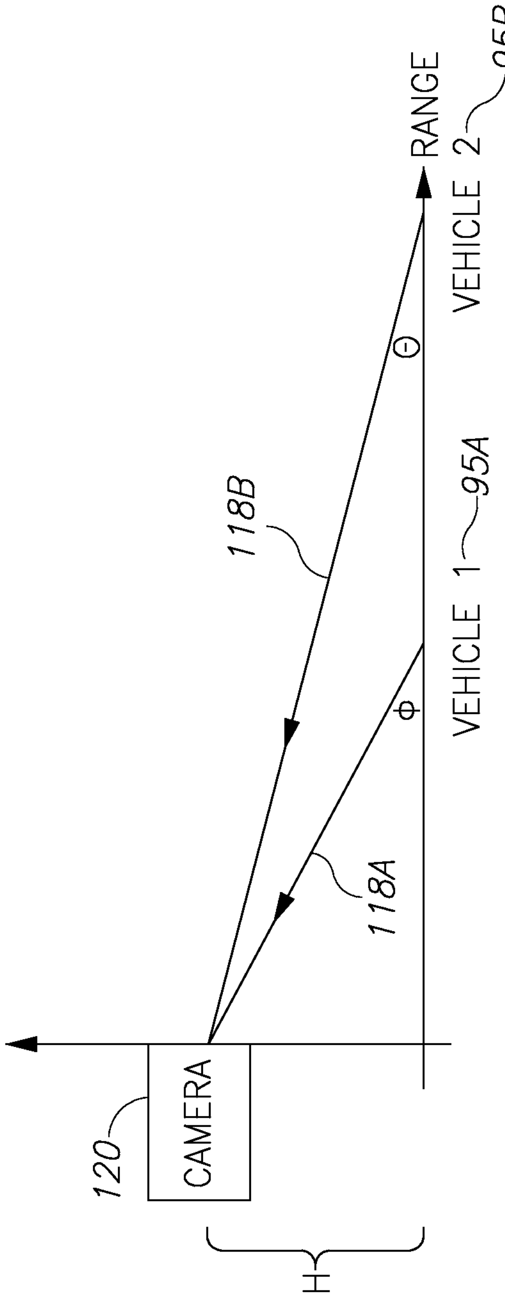


Figure 13A

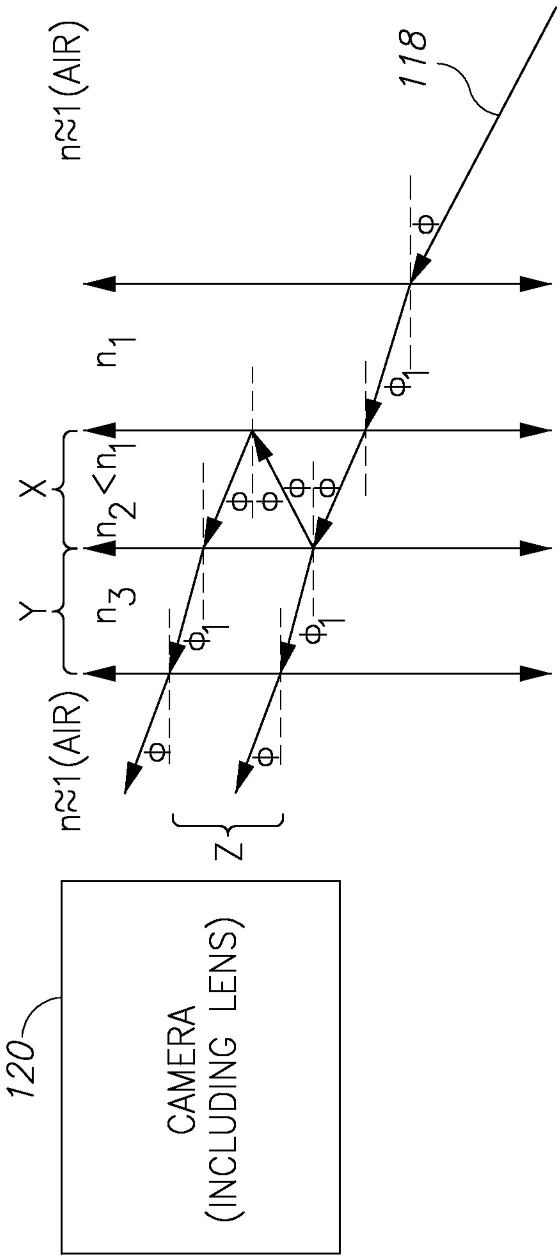


Figure 13B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2016/050770

A. CLASSIFICATION OF SUBJECT MATTER
IPC (2016.01) G01S 17/89

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)
IPC (2016.01) G01S 17/89

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Databases consulted: Esp@cenet, Google Patents, FamPat database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013086543 A2 MICROSOFT CORP. 13 Jun 2013 (2013/06/13) The whole reference	1-50
A	WO 2005076037 A1 ELBIT SYSTEMS LTD. 18 Aug 2005 (2005/08/18) The whole reference	1-50

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 Sep 2016	28 Sep 2016

Name and mailing address of the ISA:
Israel Patent Office
Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel
Facsimile No. 972-2-5651616

Authorized officer
DAVIDI Ariel
Telephone No. 972-2-5651727

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2016/050770

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
WO 2013086543 A2	13 Jun 2013	WO 2013086543 A2	13 Jun 2013
		WO 2013086543 A3	22 Aug 2013
		CN 103988161 A	13 Aug 2014
		EP 2788848 A1	15 Oct 2014
		EP 2788848 A4	01 Jul 2015
		EP 2845165 A2	11 Mar 2015
		EP 2845165 A4	19 Aug 2015
		JP 2015500533 A	05 Jan 2015
		KR 20140105738 A	02 Sep 2014
		US 2013151983 A1	13 Jun 2013
		US 9244583 B2	26 Jan 2016
		WO 2013085780 A1	13 Jun 2013
WO 2005076037 A1	18 Aug 2005	WO 2005076037 A1	18 Aug 2005
		CA 2554955 A1	18 Aug 2005
		CA 2554955 C	14 Sep 2010
		IL 160220 D0	20 Nov 2005
		IL 165090 D0	18 Dec 2005
		IL 177078 D0	10 Dec 2006
		US 2007058038 A1	15 Mar 2007
		US 8194126 B2	05 Jun 2012