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(54) **REAL-TIME ACTIVE EMERGENCY VEHICLE DETECTION**

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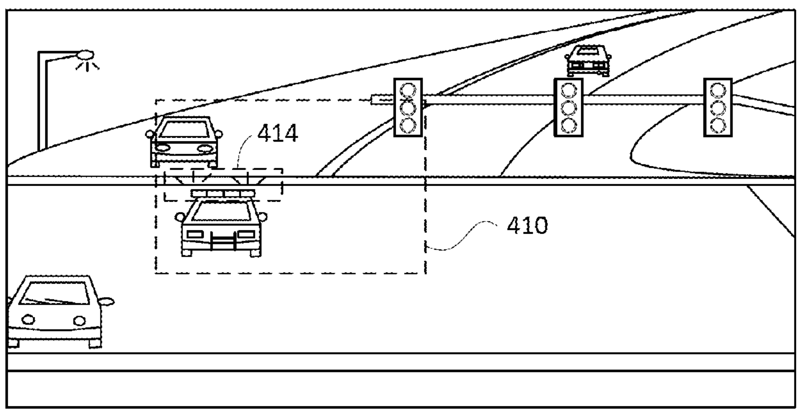
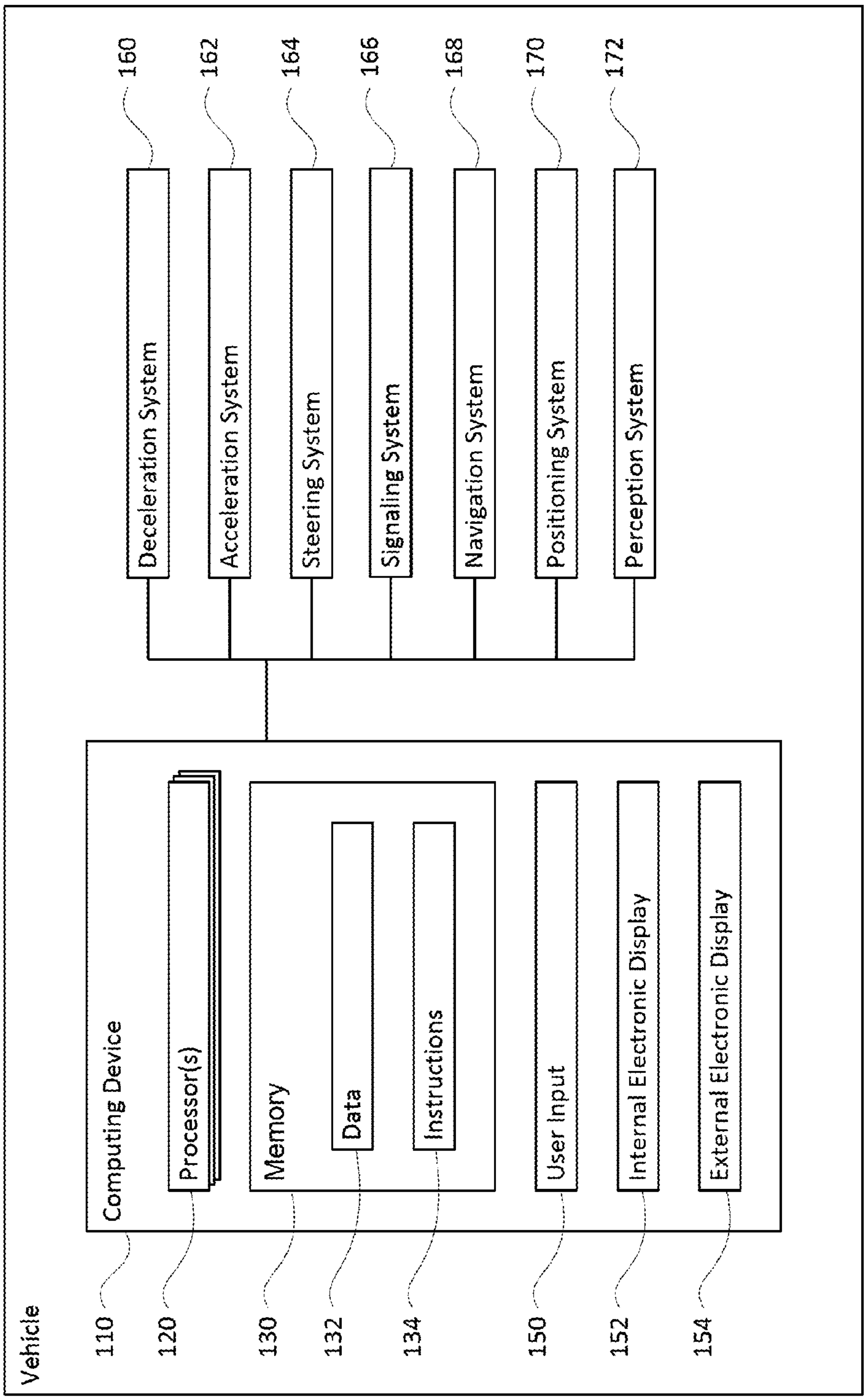
(57) **ABSTRACT**

A system and method is provided for detecting and responding to emergency vehicles. In one aspect, one or more computing devices may identify a set of light sources from an image based at least in part on one or more templates, and may filter the set of light sources in order to identify one or more light sources corresponding to a potential emergency vehicle. Moreover, the one or more computing devices may determine whether any of the one or more light sources is flashing and whether any of the one or more light sources is associated with a particular type of the potential emergency vehicle. Further, the one or more computing devices may maneuver a vehicle based on the determination to yield in response to at least one of the one or more flashing light sources and the particular type of the emergency vehicle.

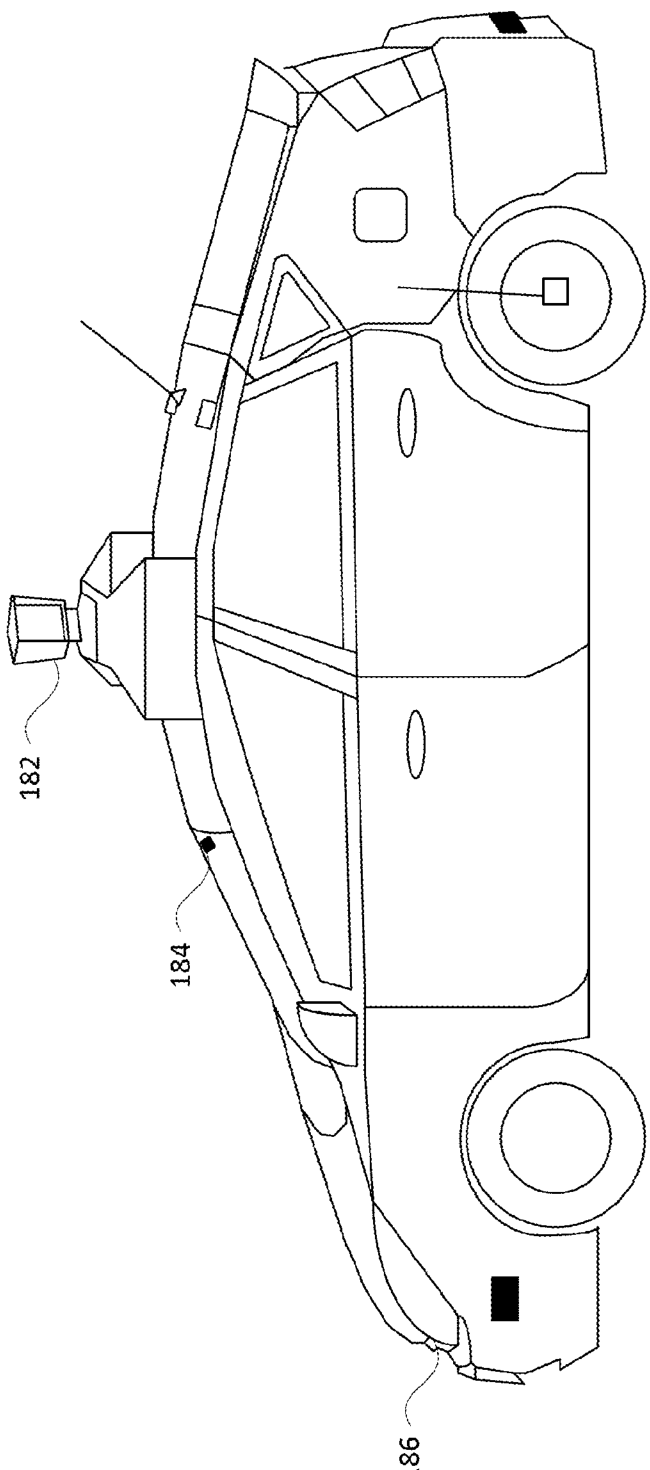
460





100

FIGURE 1A



100

FIGURE 1B

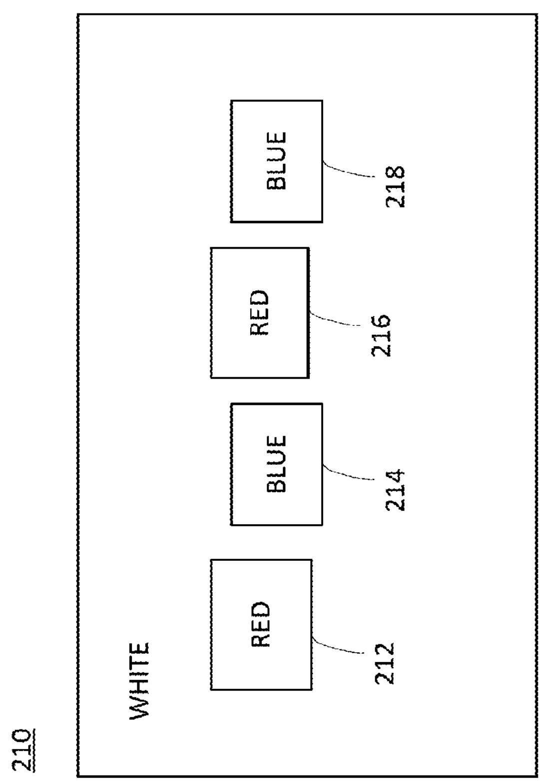


FIGURE 2A

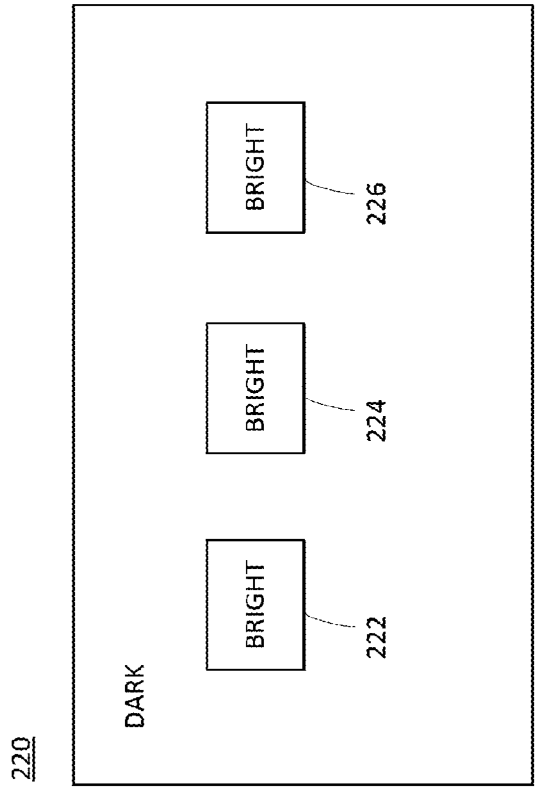


FIGURE 2B

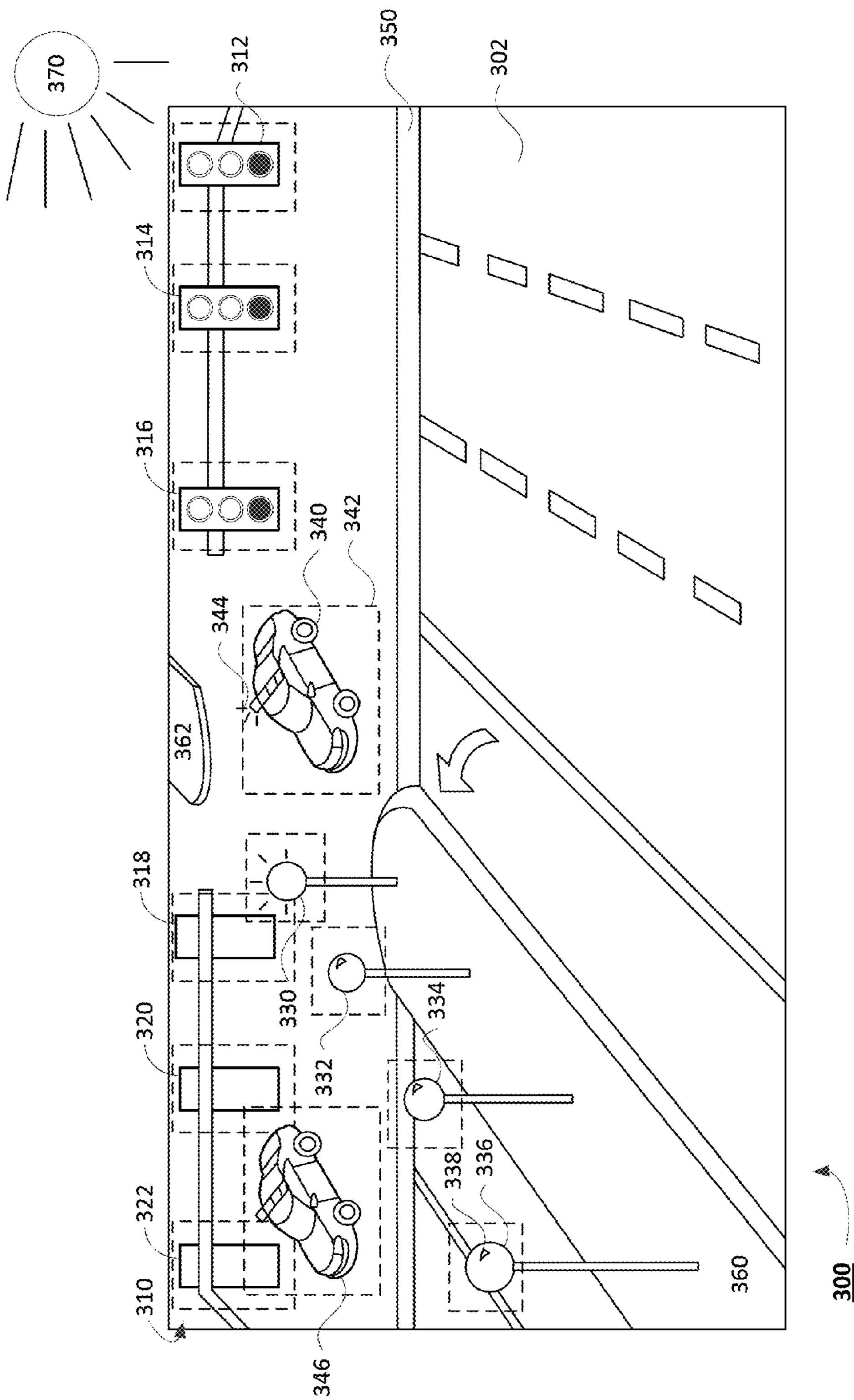

370
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FIGURE 3

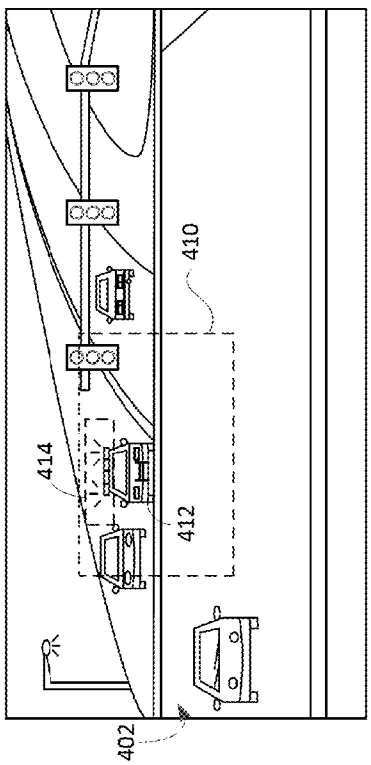


FIGURE 4A
400

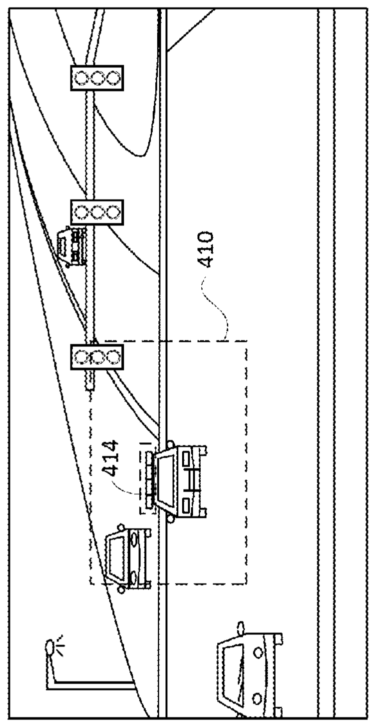


FIGURE 4B
430

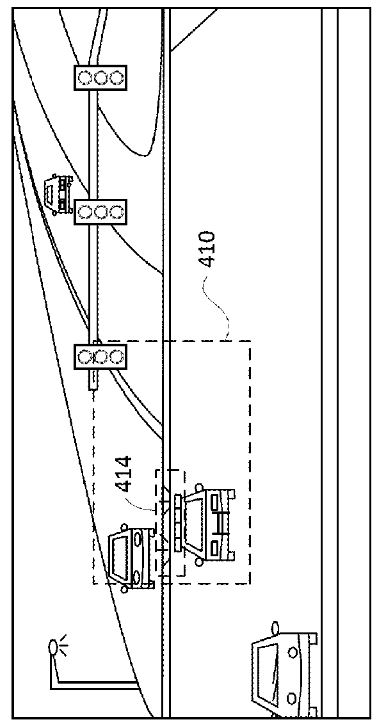
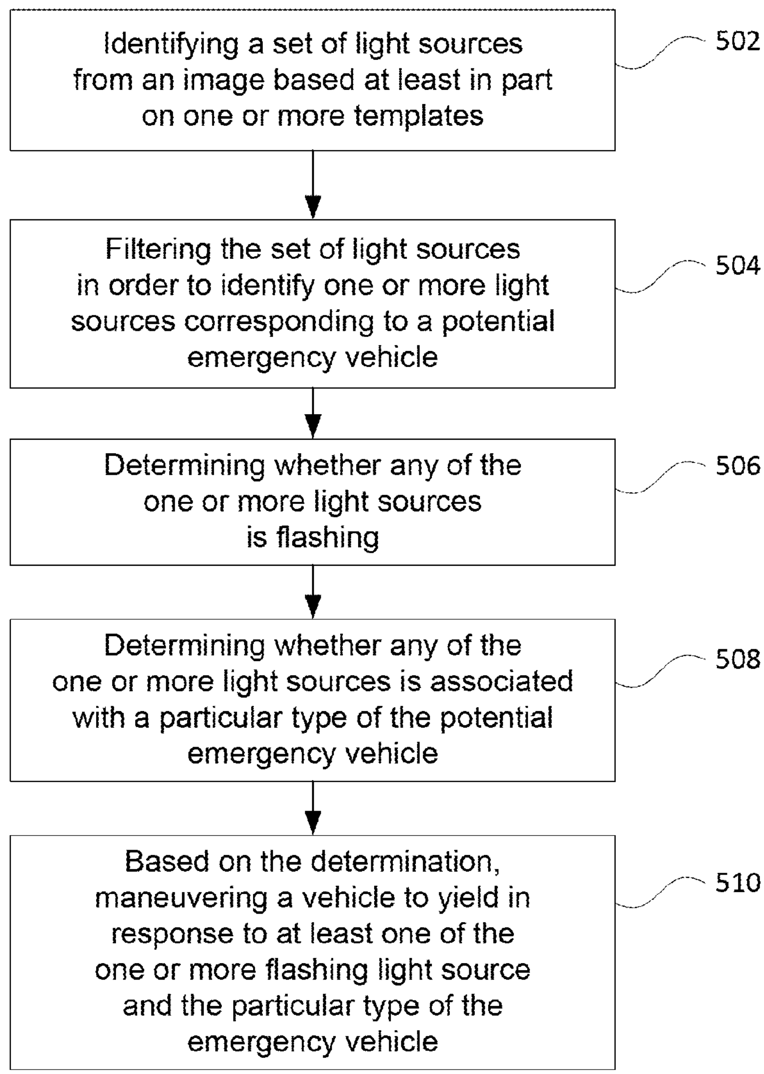


FIGURE 4C
460


Identifying a set of light sources from an image based at least in part on one or more templates
502
Filtering the set of light sources in order to identify one or more light sources corresponding to a potential emergency vehicle
504
Determining whether any of the one or more light sources is flashing
506
Determining whether any of the one or more light sources is associated with a particular type of the potential emergency vehicle
508
Based on the determination, maneuvering a vehicle to yield in response to at least one of the one or more flashing light source and the particular type of the emergency vehicle
510

500

FIGURE 5

REAL-TIME ACTIVE EMERGENCY VEHICLE DETECTION

BACKGROUND

[0001] Autonomous vehicles, such as vehicles which do not require a human driver, may be used to aid in the transport of passengers or items from one location to another. An important component of an autonomous vehicle is the perception system, which allows the vehicle to perceive and interpret its surroundings using cameras, radar, sensors, and other similar devices. The perception system executes numerous decisions while the autonomous vehicle is in motion, such as speeding up, slowing down, stopping, turning, etc. Autonomous vehicles may also use the cameras, sensors, and global positioning devices to gather and interpret images and sensor data about its surrounding environment, e.g., oncoming vehicles, parked cars, trees, buildings, etc. For example, an approaching emergency vehicle, such as a police car, having engaged its flashing lights may need to be given priority and right-of-way on the road. Thus, an autonomous vehicle may need to accurately detect and properly respond to approaching emergency vehicles.

BRIEF SUMMARY

[0002] In one aspect, a method comprises identifying, using one or more computing devices, a set of light sources from an image based at least in part on one or more templates, and filtering, using the one or more computing devices, the set of light sources in order to identify one or more light sources corresponding to a potential emergency vehicle. Moreover, the method comprises determining, using the one or more computing devices, whether any of the one or more light sources is flashing, and determining, using the one or more computing devices, whether any of the one or more light sources is associated with a particular type of the potential emergency vehicle. Based on the determination, the method comprises maneuvering, using the one or more computing devices, a vehicle to yield in response to at least one of the one or more flashing light sources and the particular type of the emergency vehicle.

[0003] In another aspect, a system is provided comprising a memory and one or more computing devices, each of the one or more computing devices having one or more processors, the one or more computing devices being coupled to the memory. The one or more computing devices are configured to identify a set of light sources from an image based at least in part on one or more templates, and filter the set of light sources in order to identify one or more light sources corresponding to a potential emergency vehicle. Moreover, the one or more computing devices are configured to determine whether any of the one or more light sources is flashing, and determine whether any of the one or more light sources is associated with a particular type of the potential emergency vehicle. Based on the determination, the one or more computing devices are configured to maneuver a vehicle to yield in response to at least one of the one or more flashing light source and the particular type of the emergency vehicle.

[0004] In yet another aspect, a non-transitory, tangible computer-readable medium on which instructions are stored, the instructions, when executed by one or more computing devices perform a method, the method comprises identifying a set of light sources from an image based at least in part on one or more templates, and filtering the set of light sources in order to identify one or more light sources corresponding to a potential emergency vehicle. Moreover, the method comprises determining whether any of the one or more light sources is flashing, and determining whether any of the one or more light sources is associated with a particular type of the potential emergency vehicle. Based on the determination, the method comprises maneuvering a vehicle to yield in response to at least one of the one or more flashing light source and the particular type of the emergency vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1**A is a functional diagram of a system in accordance with aspects of the disclosure.

[0006] FIG. **1**B is an example illustration of the vehicle of FIG. **1**A in accordance with aspects of the disclosure.

[0007] FIG. **2**A is an example of one or more templates in accordance with aspects of the disclosure.

[0008] FIG. **2**B is another example of one or more templates in accordance with aspects of the disclosure.

[0009] FIG. **3** is an example image captured by a camera in accordance with aspects of the disclosure.

[0010] FIG. **4**A is an example image associated with emergency vehicle light detection in accordance with aspects of the disclosure.

[0011] FIG. **4**B is another example image associated with emergency vehicle light detection in accordance with aspects of the disclosure.

[0012] FIG. **4**C is a further example image associated with emergency vehicle light detection in accordance with aspects of the disclosure.

[0013] FIG. **5** is an example flow diagram in accordance with aspects of the disclosure.

DETAILED DESCRIPTION

[0014] The present disclosure is directed to detecting and responding to emergency vehicles (EVs). For example, a perception system of an autonomous vehicle may capture images of its surrounding environment to detect and respond to an approaching EV. The captured images may be analyzed by one or more computing devices. The analysis may include detecting light in each of the captured images and determining whether the detected light is likely associated with an EV based on different templates. When detected light is likely associated with an EV, the one or more computing devices may determine whether the detected light is flashing. In this regard, the one or more computing devices may perform analyses on the light's spatial configuration and flash pattern to further determine whether the detected light corresponds to an EV. By doing so, the vehicle may properly identify and respond to EVs, such as by slowing down or pulling over.

[0015] In order to detect an EV, an autonomous vehicle may detect light sources being emitted near the autonomous vehicle using one or more cameras and various types of sensors. For example, a perception system of the autonomous vehicle may capture a plurality of images via one or more cameras. Moreover, the perception system may identify various objects via at least a laser-rangefinder. As such, the one or more computing devices vehicle may perform analysis on corresponding areas of the captured images and laser data to detect and respond to an approaching EV.

[0016] In one aspect, a cascaded light detection technique may be used to detect light sources from potential EVs in the captured image. For example, at least two detection stages may be used. A first detection stage may be fast and computationally cheap (e.g., low resource). A second detection stage may be more accurate than the first detection stage, but computationally expensive. During the first detection stage, the one or more computing devices may scan an entire image to rapidly identify at least all likely light sources and the colors associated therewith. During a second detection stage, the likely EV light sources may be further filtered to remove at least false positives, such as shading or sun glare.

[0017] Once light from a potential EV is detected, the one or more computing devices may determine whether that light is flashing. For example, a region where light is detected in one image may be compared to the same region in a previous image. The region may be an area around the detected light. When the light is detected in the region of the previous image, then the one or more computing devices may determine that the light is not flashing. When the light is not detected in the region of the previous image, the one or more computing device may analyze a series of image to determine whether the light is flashing.

[0018] When a flashing light is detected, the one or more computing devices may perform analysis on the light's spatial configuration and flash pattern to further determine whether the flashing light corresponds to a type of EV. For example, the one or more computing devices may determine that orange and blue flashing lights sitting together horizontally relate to a police vehicle (PV). Once the one or more computing devices determine that the flashing light corresponds to a particular type of EV, the autonomous vehicle may appropriately respond by slowing down and/or pulling over to the side of the road. When a flashing light is not detected, the autonomous vehicle may continue to operate in a normal mode.

[0019] In another aspect, flash classifiers may be trained to capture light and flash patterns for various EVs in order to improve EV detection and response. For example, numerous light configurations, flash patterns and sounds of PVs may be captured, analyzed and stored in one or more memory devices over time to be used in training a PV flash classifier. In this regard, the flash classifier may be another variable that can be used to more accurately detect and respond to an approaching EV.

[0020] The above-described features are related to the detection and analysis of light in a series of captured images. In that regard, an approaching EV may be quickly and efficiently detected regardless of the size and appearance of the EV.

[0021] As shown in FIG. **1**A, a vehicle **100** in accordance with one aspect of the disclosure includes various components. While certain aspects of the disclosure are particularly useful in connection with specific types of vehicles, the vehicle may be any type of vehicle including, but not limited to, cars, trucks, motorcycles, busses, boats, airplanes, helicopters, lawnmowers, recreational vehicles, amusement park vehicles, farm equipment, construction equipment, trams, golf carts, trains, and trolleys. The vehicle may have one or more computing devices, such as computing device **110** containing one or more processors **120**, memory **130** and other components typically present in general purpose computing devices.

[0022] The memory **130** stores information accessible by the one or more processors **120**, including data **132** and instructions **134** that may be executed or otherwise used by the processor(s) **120**. The memory **130** may be of any type capable of storing information accessible by the processor(s), including a computing device-readable medium, or other medium that stores data that may be read with the aid of an electronic device, such as a hard-drive, memory card, ROM, RAM, DVD or other optical disks, as well as other write-capable and read-only memories. Systems and methods may include different combinations of the foregoing, whereby different portions of the instructions and data are stored on different types of media.

[0023] The data **132** may be retrieved, stored or modified by processor(s) **120** in accordance with the instructions **132**. For instance, although the claimed subject matter is not limited by any particular data structure, the data may be stored in computing device registers, in a relational database as a table having a plurality of different fields and records, XML documents or flat files. The data may also be formatted in any computing device-readable format.

[0024] For example, data **132** may include one or more templates configured to detect light sources and colors thereof. The templates may be a light template, a color template, a combination of the light and color templates, or different types of image templates. For example, these templates may be used to detect light sources and whether the light sources are associated with EVs. As will be further discussed below, the one or more processors **120** of computing device **110** may use the one or more above-described templates and implement a cascaded light detection technique to identify light sources associated with EVs, and subsequently determine whether these light sources are flashing, determine the type of EV, and respond accordingly.

[0025] In another example, data **132** may also include a plurality of classifiers. One example of a classifier may be a flashing bar classifier. For instance, the flashing bar classifier may include numerous police vehicle (PV) light patterns and may be trained over time to more accurately detect different types of PVs. Other types of classifiers may be associated with ambulance light patterns, sound patterns, light configurations, etc. Further, the data **132** may also include information related to different types of EVs, e.g., types of vehicles, sizes, shapes, common sounds, flash patterns, light patterns, etc.

[0026] In a further example, data **132** may also include location information (e.g., GPS coordinates) associated with various light sources expected to be within or at a geographical area. For instance, a particular intersection may have a certain number of traffic lights, street lights, pedestrian crosswalk lights, etc. These light sources may be associated with geolocation data, such that the computing device **110** of vehicle **100** may be able to readily determine the quantity and, in some instances, the exact location of the light sources at the intersection. In this regard, the computing device **110** may be able to quickly and efficiently filter light sources that are not associated with EVs when determining whether any detected light sources likely correspond to EVs.

[0027] The instructions **134** may be any set of instructions to be executed directly (such as machine code) or indirectly (such as scripts) by the processor. For example, the instructions may be stored as computing device code on the computing device-readable medium. In that regard, the terms "instructions" and "programs" may be used interchangeably herein. The instructions may be stored in object code format for direct processing by the processor, or in any other computing device language including scripts or collections of independent source code modules that are interpreted on demand or compiled in advance. Functions, methods and routines of the instructions are explained in more detail below.

[0028] The one or more processors **120** may be any conventional processors, such as commercially available CPUs. Alternatively, the one or more processors may be a dedicated device such as an ASIC or other hardware-based processor, such as a field programmable gate array (FPGA). Although FIG. **1**A functionally illustrates the processor(s), memory, and other elements of computing device **110** as being within the same block, it will be understood by those of ordinary skill in the art that the processor, computing device, or memory may actually include multiple processors, computing devices, or memories that may or may not be stored within the same physical housing. For example, memory may be a hard drive or other storage media located in a housing different from that of computing device **110**. Accordingly, references to a processor or computing device will be understood to include references to a collection of processors or computing devices or memories that may or may not operate in parallel.

[0029] Computing device **110** may have all of the components normally used in connection with a computing device such as the processor and memory described above, as well as a user input **150** (e.g., a mouse, keyboard, touch screen and/or microphone) and various electronic displays (e.g., a monitor having a screen, a small LCD touch-screen or any other electrical device that is operable to display information). In this example, the vehicle includes an internal electronic display **152** as well as an external electronic display **154**. In this regard, internal electronic display **152** may be located within a cabin of vehicle **100** and may be used by computing device **110** to provide information to passengers within the vehicle **100**. External electronic display **154** may be located eternally or mounted on an external surface of the vehicle **100** and may be used by computing device **110** to provide information to potential passengers or other persons outside of vehicle **100**.

[0030] In one example, computing device **110** may be an autonomous driving computing system incorporated into vehicle **100**. The autonomous driving computing system may capable of communicating with various components of the vehicle. For example, returning to FIG. **1**, computing device **110** may be in communication various systems of vehicle **100**, such as deceleration system **160**, acceleration system **162**, steering system **164**, signaling system **166**, navigation system **168**, positioning system **170**, and perception system **172**, such that one or more systems working together may control the movement, speed, direction, etc. of vehicle **100** in accordance with the instructions **134** stored in memory **130**. Although these systems are shown as external to computing device **110**, in actuality, these systems may also be incorporated into computing device **110**, again as an autonomous driving computing system for controlling vehicle **100**.

[0031] As an example, computing device **110** may interact with deceleration system **160** and acceleration system **162** in order to control the speed of the vehicle. Similarly, steering system **164** may be used by computing device **110** in order to control the direction of vehicle **100**. For example, if vehicle **100** configured for use on a road, such as a car or truck, the steering system may include components to control the angle of wheels to turn the vehicle. Signaling system **166** may be used by computing device **110** in order to signal the vehicle's intent to other drivers or vehicles, for example, by lighting turn signals or brake lights when needed.

[0032] Navigation system **168** may be used by computing device **110** in order to determine and follow a route to a location. In this regard, the navigation system **168** and/or data **132** may store map information, e.g., highly detailed maps identifying the shape and elevation of roadways, lane lines, intersections, crosswalks, speed limits, traffic signals, buildings, signs, real time traffic information, vegetation, or other such objects and information.

[0033] Positioning system **170** may be used by computing device **110** in order to determine the vehicle's relative or absolute position on a map or on the earth. For example, the position system **170** may include a GPS receiver to determine the device's latitude, longitude and/or altitude position. Other location systems such as laser-based localization systems, inertial-aided GPS, or camera-based localization may also be used to identify the location of the vehicle. The location of the vehicle may include an absolute geographical location, such as latitude, longitude, and altitude as well as relative location information, such as location relative to other cars immediately around it which can often be determined with less noise that absolute geographical location.

[0034] The positioning system **170** may also include other devices in communication with computing device **110**, such as an accelerometer, gyroscope or another direction/speed detection device to determine the direction and speed of the vehicle or changes thereto. By way of example only, an acceleration device may determine its pitch, yaw or roll (or changes thereto) relative to the direction of gravity or a plane perpendicular thereto. The device may also track increases or decreases in speed and the direction of such changes. The device's provision of location and orientation data as set forth herein may be provided automatically to the computing device **110**, other computing devices and combinations of the foregoing.

[0035] The perception system **172** also includes one or more components for detecting and performing analysis on objects external to the vehicle such as other vehicles, obstacles in the roadway, traffic signals, signs, trees, etc. For example, the perception system **172** may include lasers, sonar, radar, one or more cameras, or any other detection devices which record data which may be processed by computing device **110**. In the case where the vehicle is a small passenger vehicle such as a car, the car may include a laser mounted on the roof or other convenient location.

[0036] The computing device **110** may control the direction and speed of the vehicle by controlling various components. By way of example, if the vehicle is operating completely autonomously, computing device **110** may navigate the vehicle to a location using data from the detailed map information and navigation system **168**. Computing device **110** may use the positioning system **170** to determine the vehicle's location and perception system **172** to detect and respond to objects when needed to reach the location safely. In order to do so, computing device **110** may cause the vehicle to accelerate (e.g., by increasing fuel or other energy provided to the engine by acceleration system **162**), decelerate (e.g., by decreasing the fuel supplied to the engine or by applying brakes by deceleration system **160**), change direction (e.g., by turning the front or rear wheels of vehicle **100** by steering system **164**), and signal such changes (e.g. by lighting turn signals of signaling system **166**).

[0037] FIG. **1**B is an example illustration of vehicle **100** described above. As shown, various components of the perception system **172** may be positioned on the roof of vehicle

100 in order to better detect external objects while the vehicle is engaged. In this regard, one or more sensors, such as laser range finder **182** may be positioned or mounted to the roof of vehicle **101**. Thus, the computing device **110** (not shown) may control laser range finder **182**, e.g., by rotating it 180 degrees, or one or more cameras **184** mounted internally on the windshield of vehicle **100** to receive and analyze various images about the environment. Although the laser range finder **182** is positioned on top of perception system **172** in FIG. **1**B, and the one or more cameras **184** mounted internally on the windshield, other detection devices, such as sonar, radar, GPS, etc., may also be positioned in a similar manner.

[0038] As described above, one or more templates may be stored in memory **130** of computing device **110**. FIGS. **2**A-B depict example applications of one or more templates that may be used to detect light sources and determine whether the detected light sources correspond to EVs. As shown, templates **212**, **214**, **216**, **218** may be based on at least light color to identify potential EVs in image **210**. Templates **222**, **224**, **226** may be based on at least brightness to identify potential EVs in image **220**. The one or more templates may also be based on light color, brightness, or combinations of other types of characteristics, etc. After one or more potential light sources corresponding to EVs are identified in an image, the spatial configuration of the individual light sources, size of the light sources, etc., may be used to determine the type of EV. In one example, the templates **212**, **214**, **216**, **218**, **222**, **224**, and **226** may be applied to a particular area of the images **210** and **220** captured by the one or more cameras **184** of vehicle **100**, or in other scenarios, the templates may be applied to the entire image. For instance, the particular area of the image that a template may correspond to could be a bounding box of an object (e.g., a vehicle) generated by the laser rangefinder **182** of vehicle **100**.

[0039] In addition to the operations described above and illustrated in the figures, various operations will now be described. It should be understood that the following operations do not have to be performed in the precise order described below. Rather, various steps can be handled in a different order or simultaneously, and steps may also be added or omitted.

[0040] In one aspect, the one or more templates stored in memory **130** may be used to convert an image captured by the one or more cameras **184** into a customized color-space so that certain colors (e.g., orange, yellow, blue, red, etc.) may become conspicuous. For example, a template may be applied to an image, such that the template may convert a traditional red-green-blue (RGB) color-space into a "max-R," "max-B," and "mean-RGB" color-space. For example, "max-R" and "max-B" may be defined as maximizing only the red and blue colors, respectively, and any color in the image that is not red or blue may be blended to a generally white color via the "mean-RGB" function. In this regard, any light that is either red or blue can be easily identified based on the applied template.

[0041] FIG. **2**A illustrates one or more example templates **212**, **214**, **216**, **218** corresponding to various areas of image **210**, which may be used to identify light sources in the image associated with a police vehicle (PV). In this example, the templates **212**, **214**, **216**, and **218** may be applied to a particular area of the image **210**, such as a bounding box corresponding to a vehicle. As shown, each template identifies four different light sources in a generally horizontal configuration within particular areas in image **210**. The templates **212**, **214**, **216**, and **218** may also indicate that the four light sources are emitting a red light, a blue light, another red light, and another blue light, respectively. The four light sources may be surrounded by a generally white color, e.g., mixture of the red, green, and blue light associated with a RGB color-space. In this regard, using this information derived from the templates, the computing device **110** of vehicle **100** may determine that the light sources may likely be associated with a PV based on at least the color of the lights and the spatial configuration of the four different light sources.

[0042] FIG. **2**B illustrates one or more example templates **222**, **224**, **226** corresponding to various areas of image **220**, which may be used to identify light sources in the image associated with an ambulance. Similar to the one or more templates **212**, **214**, **216**, and **218**, the one or more templates **222**, **224**, **226** may also be applied to particular areas of the image **220**. Again, the particular area may be a bounding box corresponding to a vehicle. As depicted, each template identifies three specific bright regions of the image **220** surrounded by a generally dark region. Thus, the computing device **110** may determine that these bright areas may likely be associated with light sources. Further, the computing device **110** may identify that the light sources may likely correspond to an ambulance based on at least the spatial configuration of the bright areas.

[0043] While FIGS. **2**A-B depict one or more templates based on color and brightness, respectively, an individual template may also be based on both color and brightness. And as discussed above, the templates are not limited thereto.

[0044] A vehicle may be traveling along a particular path and the perception system may be capturing images and gathering laser data of the vehicle's surrounding environment. FIG. **3** is an example image **300** captured by one or more cameras of the perception system. In this example, autonomous vehicle **100** may be traveling along road **302** and simultaneously capturing numerous images of the vehicle **100**'s surrounding environment. As the vehicle **100** approaches intersection **310** along road **302**, the one or more cameras **184** may capture the image **300** of at least the intersection **310**.

[0045] The image **300** includes various objects. For instance, the intersection **310** includes traffic lights **312**, **314**, **316**, **318**, **320**, **322**, streetlights **330**, **332**, **334**, **336**, a pedestrian crosswalk **350** perpendicular to the road **302**, medians **360** and **362**, etc. The image **300** may also include police vehicles (PVs) **340**, **346**.

[0046] The perception system **172** may identify objects based on laser data collected from the laser rangefinder **182** of vehicle **100**. For each identified object, the perception system **172** may determine a bounding box for the laser data corresponding to that object. Thus, each bounding box has a 3D geometry that includes a 3D location. This 3D location may be used to identify the locations of corresponding objects in image **300** using known techniques for detecting locations in images. The 2D locations of these bounding boxes are graphically in image **300** represented by dashed boxes, e.g., dashed box **342** around PV **340**.

[0047] The templates may be applied to an entire image or individual dashed boxes corresponding to an object. By doing so, the computing device **110** of the vehicle **100** may be configured to identify all light sources in the one or more captured images. From this set of identified light sources, the computing device may determine which lights sources (if any) within the set most likely correspond to EVs using a cascaded light detection technique including multiple detection stages.

[0048] During a first detection stage, the computing device **110** may quickly analyze all the objects in the image **300** and ultimately identify that light is being emitted from traffic lights **312**, **314**, **316**, streetlights **330**, **332**, **334**, **336**, and PV **340** based on the one or more templates stored in the memory **130**. Subsequently, during a second detection stage, the computing device **110** may more accurately determine whether any of the identified light sources correspond to the characteristics of an EV.

[0049] As noted above, during the first detection stage, the computing device **110** may quickly scan the entire image **300** and identify potential light sources. The first detection stage may be a fast, a computationally cheap, and/or a low resource-consuming technique. For instance, the first detection stage may generally look for the epicenter of the light sources, e.g., the brightest areas of the image **300**. In another instance but not limited thereto, the first detection stage may identify the brightest area of the image, local areas of the image that contain a bright spot surrounded by the dark regions, etc.

[0050] Because the first detection stage attempts to quickly identify only the bright areas of the image **300**, light sources either unrelated to EVs or false positives, such as glare from sun **370**, may be included in the identified set of light sources. For example, using templates **210** or **220**, or a combination thereof, the computing device **110** may rapidly identify that the traffic lights **312**, **314**, **316**, the streetlights **330**, **332**, **334**, **336**, and PV **340** are all light sources. As illustrated, however, only streetlight **330** is emitting light. Streetlights **332**, **334**, and **336** are reflecting light from the sun **370**. Further, the computing device **110** may identify only the light being emitted from traffic lights **312**, **314**, **316**, and not traffic lights **318**, **320**, and **322** since they face-away from the one or more cameras **184**.

[0051] In order to remove any false positives and filter out potential light sources that may be unrelated to EVs, the second detection stage may be used. The second detection stage may more accurately analyze a larger area around an epicenter of the identified light source and analyze associated colors to determine whether the light source corresponds to a potential EV. For example, a sun glare on a streetlight may have a brightness concentrated at the epicenter of the identified light source. Based on at least this characteristic of the sun glare, a computing device may filter out the sun glare. The filtering may be performed during the second detection stage.

[0052] A light source truly emitting light may exhibit gradually decreasing brightness levels from the epicenter of the light source. In addition, the colors of the lights may also be analyzed to further determine whether the light source is originating from an EV. In that regard, the one or more computing device may more accurately include the light sources that correspond to EVs during the second detection stage by using various filtering techniques.

[0053] In one example, light sources that exhibit certain characteristics associated with false positives may be excluded from the identified set of light sources. For example, during the second light detection stage, the computing device **110** may filter out any false positives, such as streetlights **332**, **334** and **336**. Unlike streetlight **330**, the streetlights **332**, **334** and **336** are turned-off and reflect sunlight from the sun **370** in the form of glare, e.g., glare **336**. As noted above, these glares may have been identified in the first detection stage.

[0054] In another example, light sources that exhibit color (s) that may be unrelated to colors associated with EV light sources may be excluded from the identified set of light sources. For instance, while streetlight **330** is actually emitting light, it may be emitting white light. In this regard, the computing device **110** may filter streetlight **330** from the identified light sources based on the color of the light and because the color is unrelated to colors of light associated with EVs, e.g., red, blue, etc.

[0055] In a further example, light sources that may be known to be unassociated with EVs based on geographical location data may be excluded from the set of the identified light sources. By way of example only, the computing device **110** may access information stored in memory **130** and determine that there are six traffic lights located at the intersection **310** based on the accessed information. The information may be at least geographical location data corresponding to the traffic lights. In other instances, the information may be static map information that may have been previously collected and stored. Based on this determination, the computing device **110** may exclude the traffic lights from the set of the identified light sources.

[0056] In other examples, light sources that exhibit characteristics associated with potential EVs may be identified to be further analyzed for flashing lights and to determine the type of EV. The computing device **110** may determine that light **344** emitted from PV **340** and the corresponding colors of light **344** are associated with the characteristics of an EV, particularly a PV. The color of light **344** may be red and blue. Further, the horizontal configuration of the light **344** may also indicate that the light may be associated with a PV.

[0057] The one or more computing devices of an autonomous vehicle may also determine whether light from the filtered light sources is flashing, e.g., whether the EV is involved in an emergency situation. For example, by analyzing multiple images, the computing device **110** may determine whether a light source corresponding to a potential EV is flashing. In that regard, a particular region of one image may be compared to the same region in a previous image. When the light source is emitting light in both images, the computing device **110** may determine that the light source is not flashing. In that regard, an on-off-on-off pattern among a series of images may indicate that the light source is flashing.

[0058] For example, FIGS. **4**A-C depict three consecutive images (or frames) of the same intersection captured by the one or more cameras **184** of vehicle **100**. FIG. **4**A is an example image **400** of an intersection **402**. In the image **400**, an EV is approaching vehicle **100**. The computing device **110** may have determined that light source **414** associated with object **412** corresponds to a potential EV based on the application of the first and second detection stages described above. In order to determine whether the light source **414** is flashing, an area corresponding to region **410** within other images may be analyzed. In this regard, the computing device **110** may analyze the same region **410** in a subsequent captured image and determine whether the light source **414** is still emitting light.

[0059] FIG. **4**B is another example image **430** of the intersection **402** that the camera **184** captures after image **400**. The computing device **110** again focuses on the region **410** to determine whether the light source **414** is still emitting light. As shown, the light source **414** is not emitting light within region **410**. Thus, at this point of analysis, the light source **414** is exhibiting an on-off pattern. However, the computing device **110** may need to analyze at least one more image to determine whether the light source **414** is flashing.

[0060] FIG. **4**C is yet another example image **460** of the intersection **402** that the camera **184** of vehicle **100** captures subsequent to image **430**. In this example, the object **412** shifts to the bottom left corner of the region **410** and has moved closer to the one or more cameras **184** compared to image **430**. In addition, the light source **414** is again emitting light. In that regard, the computing device **110** may determine that the on-off-on pattern among images **400**, **430**, and **460** indicates that the light source **414** is flashing. In an alternative example, if the computing device determines that light is still being emitted, the computing device may determine that the light source **414** is not flashing.

[0061] FIGS. **4**A-C depict three images of the same intersection **402** that are used to determine whether the light source **414** is flashing, though more or less images may be used in other flash detection scenarios.

[0062] Once light sources corresponding to a potential EV are determined to be flashing, the computing device **110** may consider other factors before responding to the potential EV, such as the spatial configuration of such light sources. For example, the light source **414** in FIGS. **4**A-C are configured in a generally horizontal manner. Based on the spatial configuration of the light source **414** and/or the comparison between the flash pattern of the light source **414** with one or more classifiers stored in memory **130**, the computing device **110** may determine that the object **412** is a police vehicle (PV). Upon determining that the flashing light source corresponds to a PV, the autonomous vehicle may appropriately respond by slowing down and/or pulling over to the side of the road.

[0063] FIG. **5** is a flow diagram **500** in accordance with aspects of the disclosure. By way of example only, one or more computing devices, such as the computing device **110** of vehicle **100**, may identify a set of light sources from an image based at least in part on one or more templates, at block **502**. As described above, the one or more templates may be based on color, brightness, or a combination thereof. The identification of the set of light sources at block **502** may be performed during a first detection stage, which allows the computing device **110** to rapidly identify potential light sources in the image. During the first detection stage, potential light sources that do not correspond to EVs may be identified (e.g., false positives), and thus, the identified light sources may be filtered.

[0064] At block **504**, the computing device **110** may filter the set of light sources in order to identify one or more light sources corresponding to a potential EV. In one example, false positives such as sun glare may be filtered out. In another example, light sources associated with colors that are unrelated to an EV may also be filtered out. In yet a further example, light sources that may be known to be unassociated with an EV based on geographical location data may be filtered out. Upon filtering the identified set of light sources at block **502**, the computing device **110** may determine whether any of the one or more light sources is flashing, at block **506**. As discussed above, whether the one or more light sources are flashing may be based on the analysis of multiple images.

[0065] At block **508**, the computing device **110** may determine whether any of the one or more light sources is associated with a particular type of the potential EV. The type of EV may be determined based on at least the spatial configuration of the light sources and/or the flash pattern of the light sources. Based on the determination, the computing device **110** may maneuver a vehicle to yield in response to at least one of the one or more flashing light sources and the particular type of the emergency vehicle. For instance, if the computing device **110** determines that an approaching EV is a PV, it may yield to the PV by pulling over to a side of a road.

[0066] Unless otherwise stated, the foregoing alternative examples are not mutually exclusive, but may be implemented in various combinations to achieve unique advantages. As these and other variations and combinations of the features discussed above can be utilized without departing from the subject matter defined by the claims, the foregoing description of the embodiments should be taken by way of illustration rather than by way of limitation of the subject matter defined by the claims. In addition, the provision of the examples described herein, as well as clauses phrased as "such as," "including" and the like, should not be interpreted as limiting the subject matter of the claims to the specific examples; rather, the examples are intended to illustrate only one of many possible embodiments. Further, the same reference numbers in different drawings can identify the same or similar elements.

1. A method comprising:

identifying, using one or more computing devices, a set of light sources from an image based at least in part on one or more templates;

filtering, using the one or more computing devices, the set of light sources in order to identify two or more light sources corresponding to a given potential emergency vehicle;

determining, using the one or more computing devices, that the two or more light sources is flashing;

determining, using the one or more computing devices, that the two or more light sources are associated with a particular type of the emergency vehicle by analyzing a relative spatial configuration of the two or more light sources and the determination that the two or more light sources are flashing; and

based on the determination that the two or more light sources are associated with the particular type of the emergency vehicle, maneuvering, using the one or more computing devices, a vehicle to yield in response to the given potential emergency vehicle.

2. (canceled)

3. The method of claim **1**, wherein determining that the two or more light sources are associated with the particular type of emergency vehicle includes at least analyzing a flash pattern of the two or more light sources and comparing the flash pattern to one or more classifiers.

4. The method of claim **1**, wherein filtering the set of light sources includes discarding light sources exhibiting one or more characteristics associated with a false positive for sun glare.

5. The method of claim **1**, wherein filtering the set of light sources includes discarding light sources exhibiting one or more colors unrelated to colors associated with emergency vehicles.

6. The method of claim **1**, wherein filtering the set of light sources includes discarding light sources unassociated with potential emergency vehicles based on at least geographical location data.

7. The method of claim **1**, wherein filtering the set of light sources includes including light sources exhibiting one or more characteristics associated with potential emergency vehicles.

8. A system comprising:
a memory;
one or more computing devices, each of the one or more computing devices having one or more processors, the one or more computing devices being coupled to the memory;
wherein the one or more computing devices are configured to:
identify a set of light sources from an image based at least in part on one or more templates;
filter the set of light sources in order to identify two or more light sources corresponding to a given potential emergency vehicle;
determine that the two or more light sources are flashing;
determine that the two or more light sources are associated with a particular type of the emergency vehicle by analyzing a relative spatial configuration of the two or more light sources with respect to the potential emergency vehicle and the determination that the two or more light sources are flashing; and
based on the determination that the two or more light sources are associated with the particular type of the emergency vehicle, maneuver a vehicle to yield in response to the given potential emergency vehicle.

9. (canceled)

10. The system of claim **8**, wherein the determination that the two or more light sources are associated with the particular type of emergency vehicle includes at least analysis of a flash pattern of the two or more light sources and comparison of the flash pattern to one or more classifiers.

11. The system of claim **8**, wherein the filtration of the set of light sources includes discarding light sources exhibiting one or more characteristics associated with a false positive for sun glare.

12. The system of claim **8**, wherein the filtration of the set of light sources includes discarding light sources exhibiting one or more colors unrelated to colors associated with emergency vehicles.

13. The system of claim **8**, wherein the filtration of the set of light sources includes discarding light sources unassociated with potential emergency vehicles based on at least geographical location data.

14. The system of claim **8**, wherein the filtration of the set of light sources includes including light sources exhibiting one or more characteristics associated with potential emergency vehicles.

15. A non-transitory, tangible computer-readable medium on which instructions are stored, the instructions, when executed by one or more computing devices perform a method, the method comprising:
identifying a set of light sources from an image based at least in part on one or more templates;
filtering the set of light sources in order to identify two or more light sources corresponding to a given potential emergency vehicle;
determining that the two or more light sources is flashing;
determining that the two or more light sources is associated with a particular type of the emergency vehicle by analyzing a spatial configuration of the two or more light sources with respect to the potential emergency vehicle and the determination that the two or more light sources are flashing; and
based on the determination that the two or more light sources is associated with the particular type of the emergency vehicle, maneuvering a vehicle to yield in response to the given particular emergency vehicle.

16. (canceled)

17. The non-transitory, tangible computer-readable medium of claim **15**, wherein determining whether two or more light sources are associated with the particular type of the emergency vehicle includes at least analyzing a flash pattern of the one or more flashing light sources and comparing the flash pattern to one or more classifiers.

18. The non-transitory, tangible computer-readable medium of claim **15**, wherein filtering the set of light sources includes discarding light sources exhibiting one or more characteristics associated with a false positive for sun glare.

19. The non-transitory, tangible computer-readable medium of claim **15**, wherein filtering the set of light sources includes discarding light sources exhibiting one or more colors unrelated to colors associated with potential emergency vehicles.

20. The non-transitory, tangible computer-readable medium of claim **15**, wherein filtering the set of light sources includes discarding light sources unassociated with potential emergency vehicles based on at least geographical location data.

21. The method of claim **1**, wherein identifying the set of light sources from the image based at least in part on one or more templates includes:
using a first template including areas corresponding to a specific arrangement of colors of light to identify at least some light sources of the set of light sources; and
using a first template including areas corresponding to a specific arrangement of brightness regions to identify at least some light sources of the set of light sources.

22. The method of claim **1**, wherein identifying the set of light sources from the image based at least in part on one or more templates includes using a template to convert the image to a customized color space so that a pre-defined set of colors are depicted in the customized color space.

23. The method of claim **22**, wherein the customized color space consists of a maximum red value, a maximum blue value, and a third non red or blue value.

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