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(54) **SYSTEMS FOR MITIGATING RADIO-FREQUENCY RADIATION EXPOSURE USING POWER INTERRUPTERS**

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(52) **U.S. Cl.**
CPC *G08C 17/02* (2013.01)

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CPC G08C 17/02; G01R 29/0814; G01R 29/0871; G01R 29/0878; G01R 29/0892; G01R 29/10; H01Q 1/42; H04B 17/101; H04B 17/30; H04B 17/354
See application file for complete search history.

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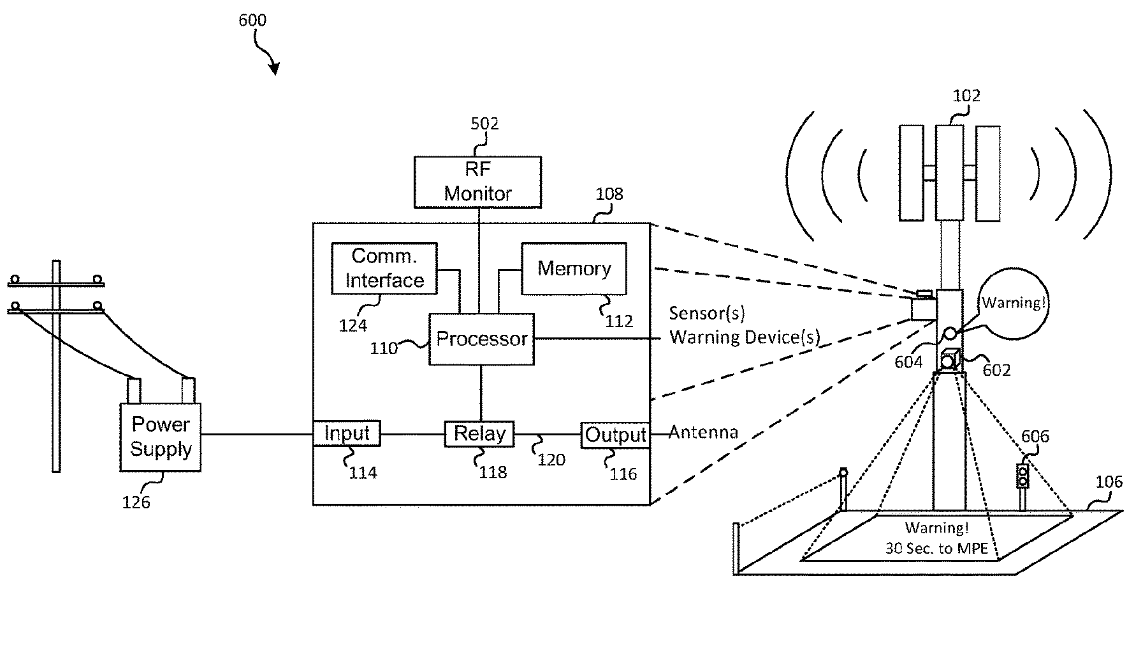
(74) *Attorney, Agent, or Firm* — Kory D. Christensen

(57) **ABSTRACT**

An RF infrastructure sentry system includes one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source and an RF mitigation system operatively connected to the one or more sensors. The RF mitigation system includes an electrical input operatively connected to a power supply for the RF radiation source; an electrical output operatively connected to the RF radiation source; a relay disposed on an electrical path between the electrical input and the electrical output and configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path; and a processor operatively connected to the relay and configured, at least in response to detection by the one or more sensors that the object has entered the area of concern, to open the relay to temporarily interrupt power to the RF radiation source.

21 Claims, 7 Drawing Sheets



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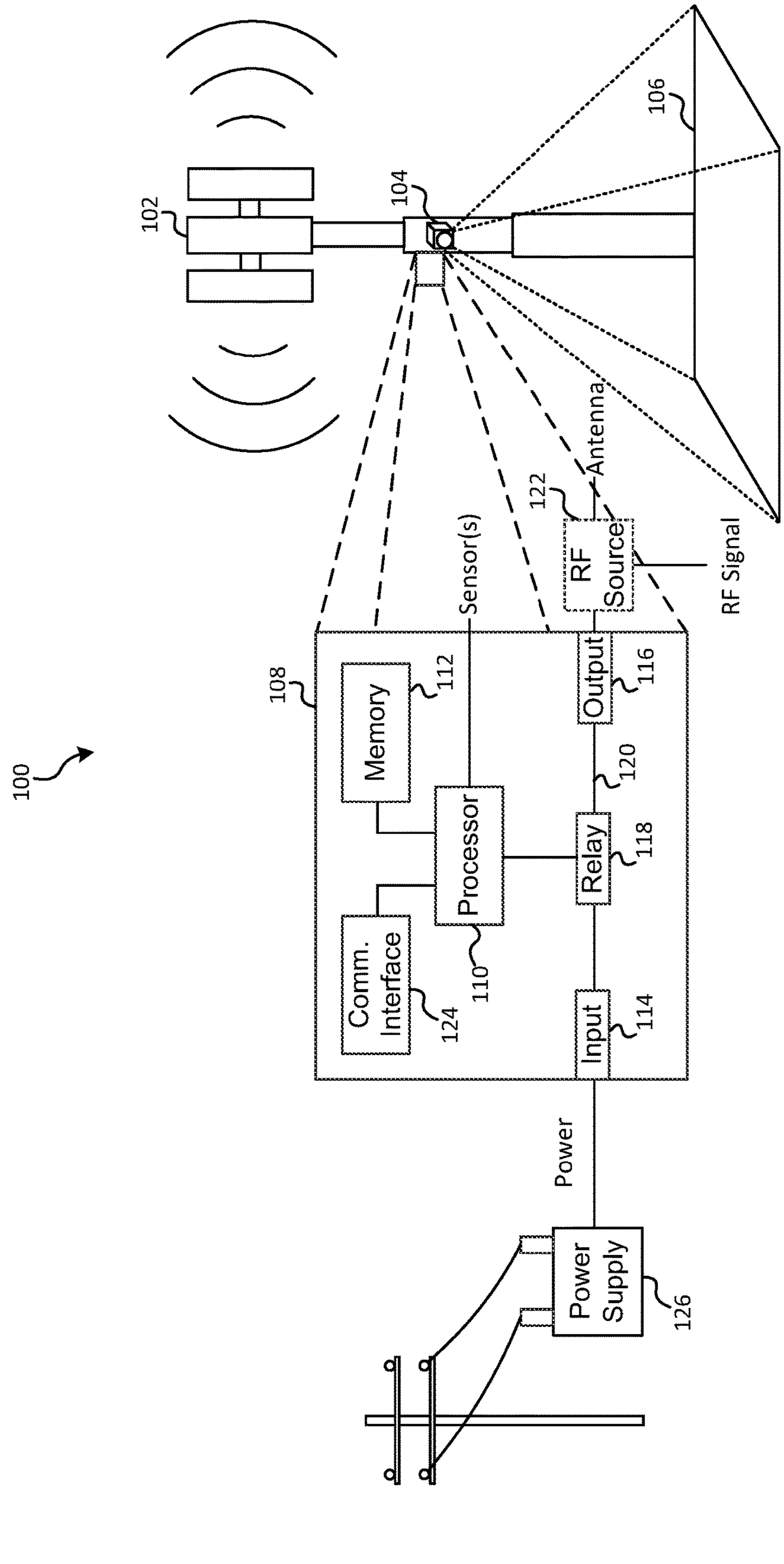

100
102
104
106
108
Memory
112
Sensor(s)
Processor
110
Comm. Interface
124
Input
114
Relay
118
120
Output
116
RF Source
122
Antenna
RF Signal
Power
Power Supply
126

FIG. 1

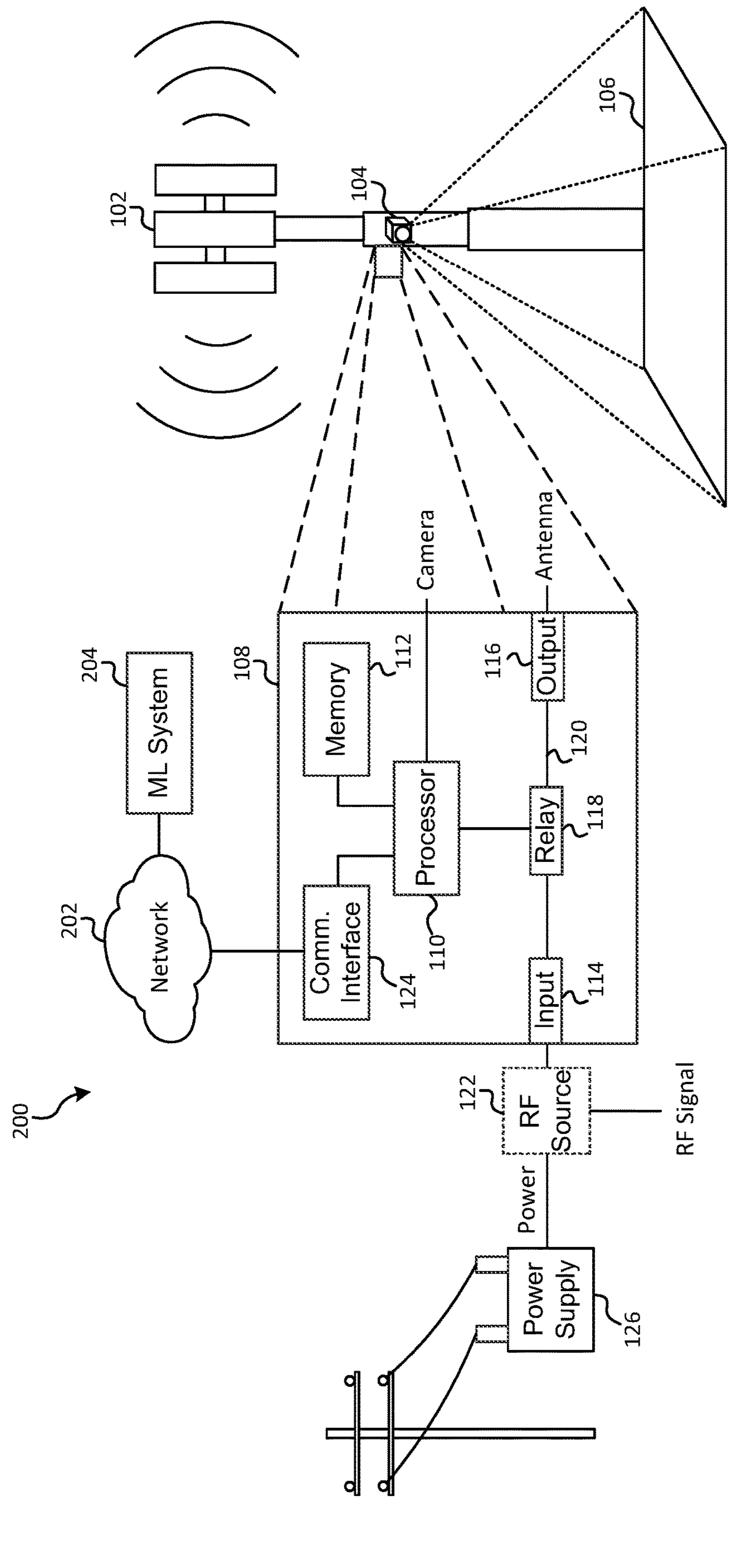

200
102
104
106
108
Memory
112
Processor
110
Comm. Interface
124
Camera
Antenna
Output
116
120
Relay
118
Input
114
ML System
204
Network
202
RF Source
122
RF Signal
Power
Power Supply
126

FIG. 2

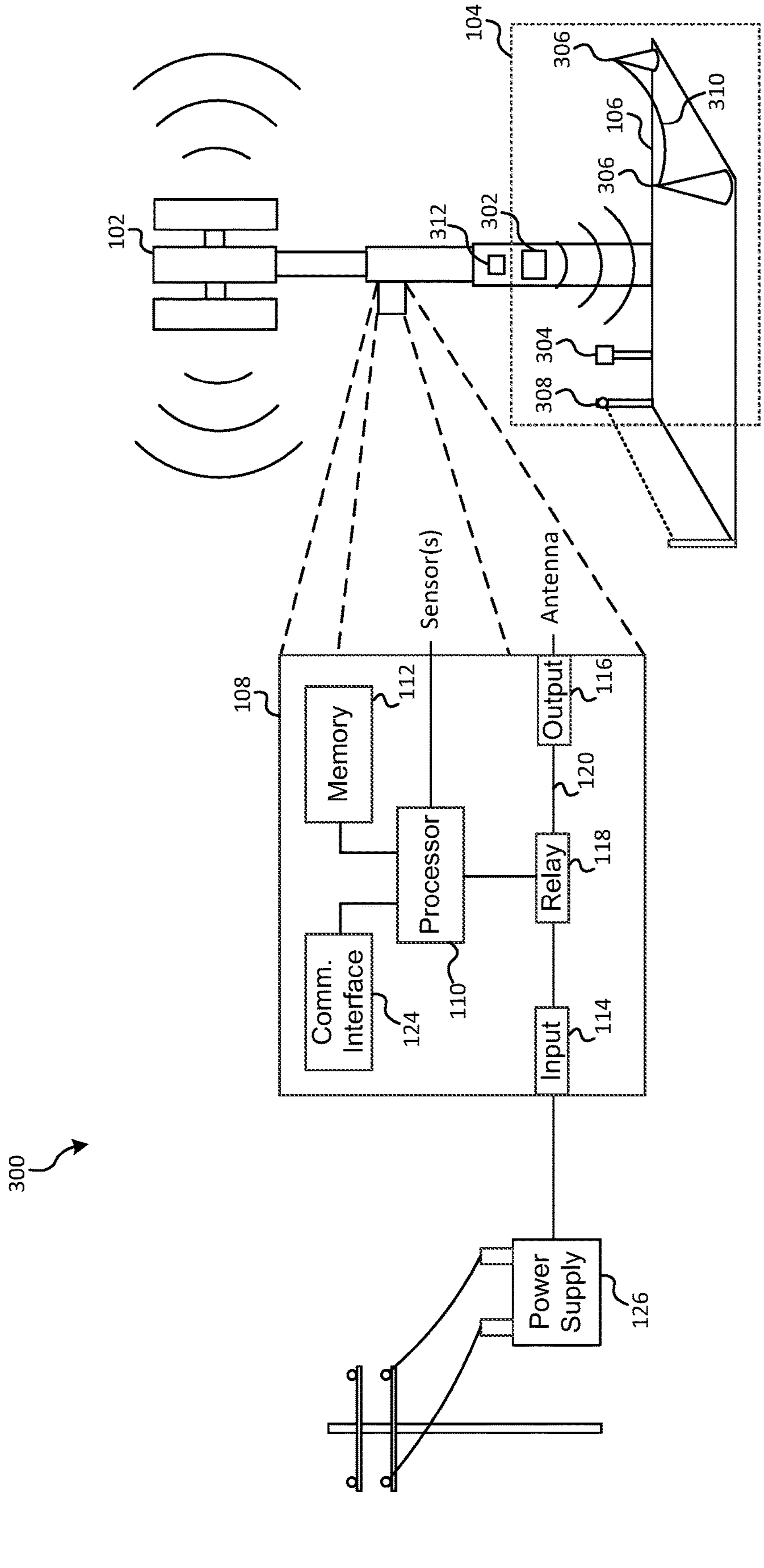

300
102
312
302
104
306
106
310
306
304
308
Sensor(s)
Antenna
108
Memory
112
Processor
110
Comm. Interface
124
Output
116
120
Relay
118
Input
114
Power Supply
126

FIG. 3

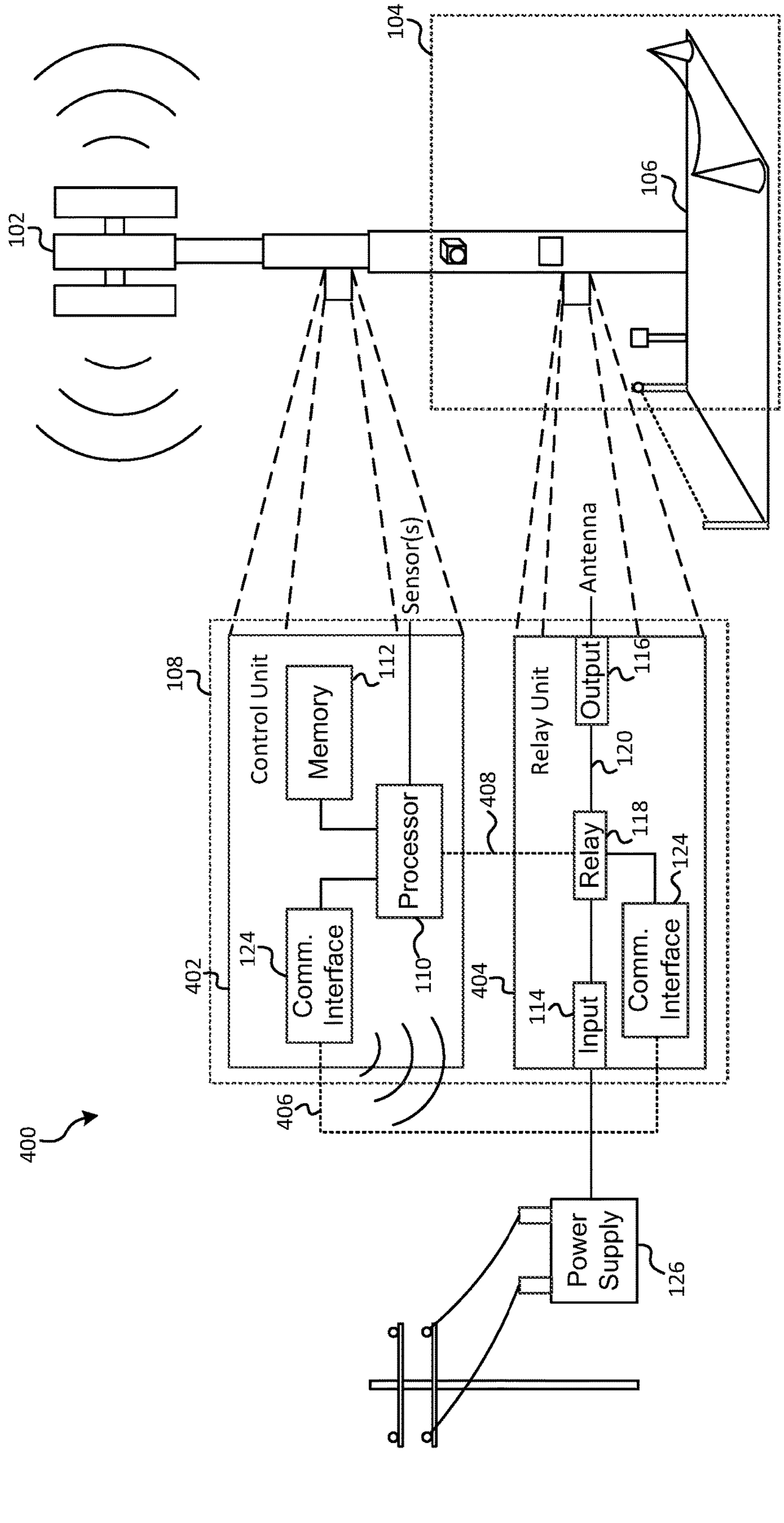
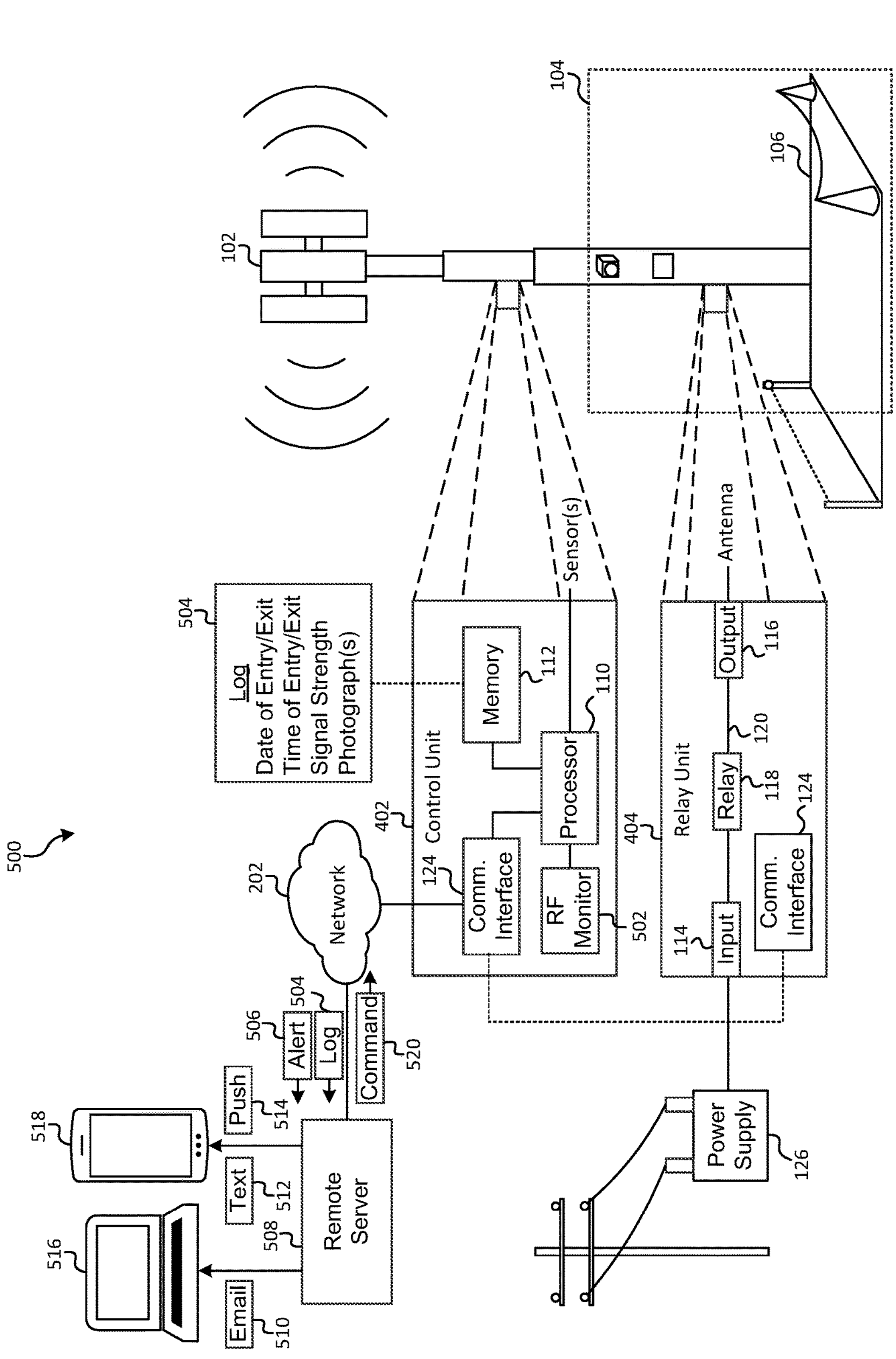

400
102
104
106
108
Control Unit
Memory
112
Processor
110
Comm. Interface
124
Sensor(s)
402
404
Relay Unit
Output
116
120
Relay
118
Comm. Interface
124
Input
114
Antenna
408
406
Power Supply
126

FIG. 4



500
102
104
106
Log
Date of Entry/Exit
Time of Entry/Exit
Signal Strength
Photograph(s)
504
Sensor(s)
Antenna
402
Control Unit
Memory
112
Processor
110
Comm.
Interface
124
RF
Monitor
502
404
Relay Unit
Output
116
Relay
118
120
Input
114
Comm.
Interface
124
Network
202
Alert
506
Log
504
Command
520
Push
514
Text
512
Email
510
Remote
Server
508
518
516
Power
Supply
126

FIG. 5

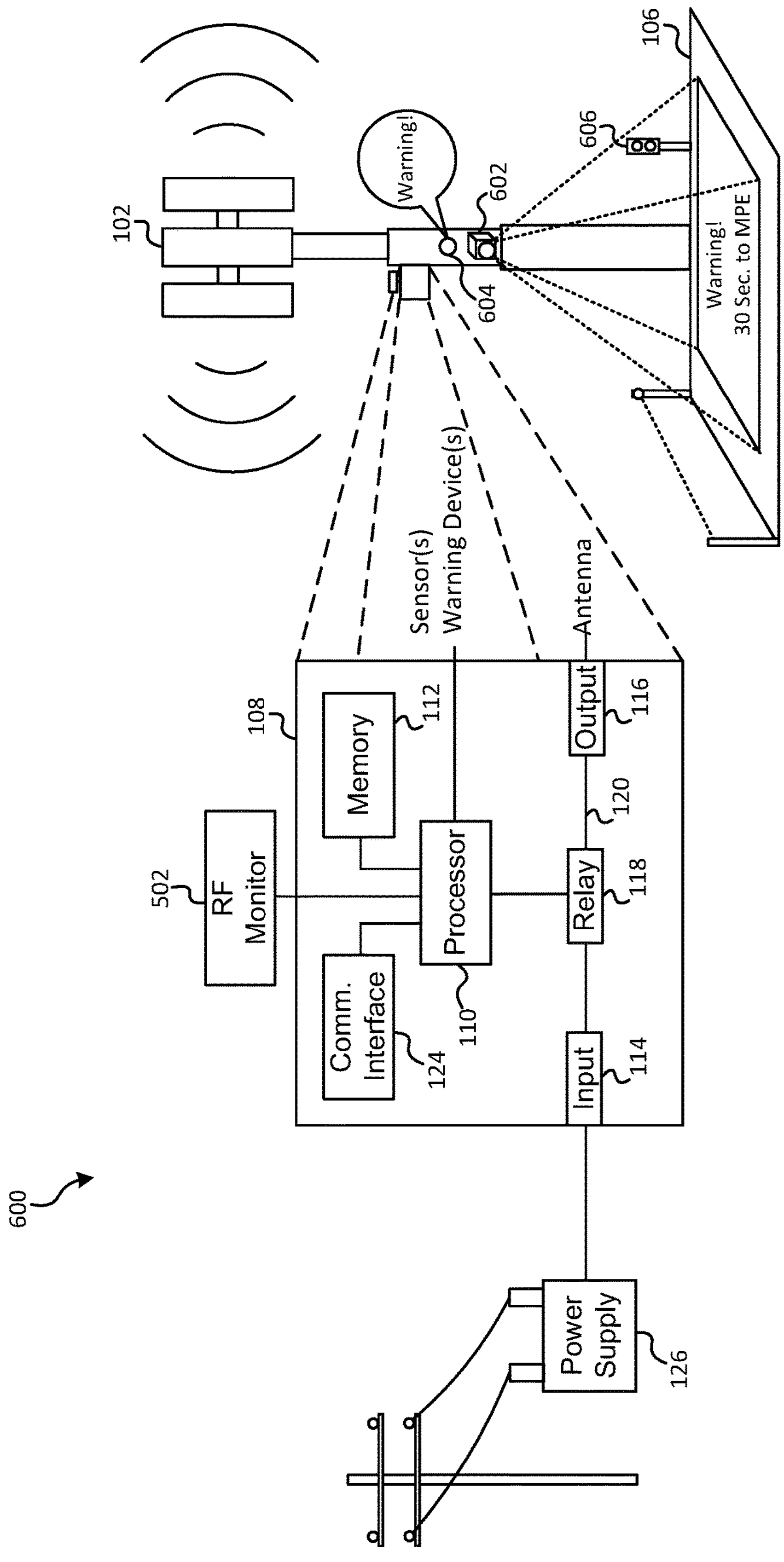

102
106
606
Warning!
602
604
Warning!
30 Sec. to MPE
Sensor(s)
Warning Device(s)
Antenna
108
Memory
112
Output
116
120
502
RF Monitor
Processor
Relay
118
Comm. Interface
124
110
Input
114
600
Power Supply
126

FIG. 6

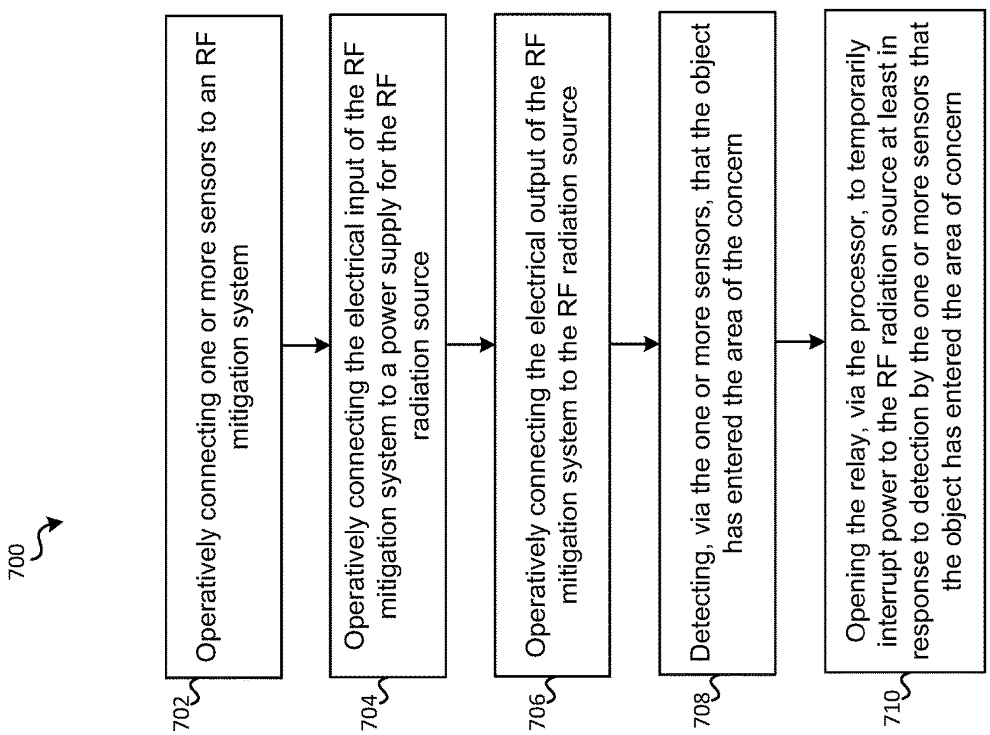

700
Operatively connecting one or more sensors to an RF mitigation system
702
Operatively connecting the electrical input of the RF mitigation system to a power supply for the RF radiation source
704
Operatively connecting the electrical output of the RF mitigation system to the RF radiation source
706
Detecting, via the one or more sensors, that the object has entered the area of the concern
708
Opening the relay, via the processor, to temporarily interrupt power to the RF radiation source at least in response to detection by the one or more sensors that the object has entered the area of concern
710

FIG. 7

SYSTEMS FOR MITIGATING RADIO-FREQUENCY RADIATION EXPOSURE USING POWER INTERRUPTERS

TECHNICAL FIELD

The present application relates to radio-frequency (RF) communication and, more specifically, to systems for mitigating RF radiation exposure in proximity to RF radiation sources, such as cell towers.

BACKGROUND

Wireless carriers are required by the Federal Communications Commission (FCC) and other government agencies to comply with a myriad of regulations and guidelines pertaining to RF emissions and human exposure at their transmission sites. In addition, the FCC has recently expanded the rules beyond wireless carriers to infrastructure firms, building owners, and any party with personnel performing work at or near a wireless transmission site.

Conventionally, owners of wireless transmission sites, such as cell towers, have placed printed warnings at or near the sites to warn personnel of the of risk of exposure to RF radiation levels that exceed the permissible limit, i.e., the maximum permissible exposure (MPE). However, such signs do nothing to tell the personnel whether the site is currently operational and therefore a hazard. Furthermore, the personnel may not see the signs or may choose to ignore them.

Similarly, barriers are an imperfect solution because they can interfere with network performance and, like signs, do not tell an on-site worker or other visitors whether RF radiation at the site exceeds the MPE. Workers can intentionally climb over barriers or unknowingly enter areas where they are exposed to elevated levels of RF radiation, potentially subjecting the owner of the site to civil liability or regulatory action.

SUMMARY

The present disclosure includes RF infrastructure sentry (RFIS) systems and associated methods that solve the disadvantages with conventional approaches to complying with FCC regulations and mitigating RF radiation exposure in proximity to an RF radiation source, such as an RF antenna.

In one aspect, an RFIS system includes one or more sensors configured to detect entry of an object into an area of concern proximate to an RF radiation source. Additionally, the RFIS system includes an electrical input operatively connected to a power supply for the RF radiation source. The RF mitigation system also includes an electrical output operatively connected to the RF radiation source. Additionally, the RF mitigation system includes a power interrupter, such as a relay, disposed on an electrical path between the electrical input and the electrical output. The relay is configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path. The RF mitigation system further includes a processor operatively connected to the relay. The processor is configured, at least in response to detection by the one or more sensors that the object has entered the area of concern, to open the relay to temporarily interrupt power to the RF radiation source.

In some configurations, the processor is further configured to close the relay to automatically restore the power to

the RF radiation source at least in response to the one or more sensors detecting that the object has exited the area of concern.

In certain configurations, the one or more sensors include an artificial intelligence (AI) camera configured to distinguish a human from other types of objects. In other configurations, the one or more sensors includes a camera, and the RF mitigation system includes a communication interface operatively connected to the camera and configured to transmit images or video captured by the camera via a network to a machine learning system configured to distinguish a human from other types of objects. The machine learning system includes a trained neural network in certain implementations.

In various configurations, the one or more sensors include at least one of a proximity sensor, a motion detector, a barrier tip/move sensor, or a photoelectric beam sensor, one or more of which may operate in concert with the camera or the AI camera.

In many configurations, the electrical input, the electrical output, and the relay are components of a relay unit disposed remotely from a control unit including the processor.

In some implementations, the control unit includes a first communication interface configured to communicate with a second communication interface included in the relay unit, the second communication interface being operatively connected to the relay. In various configurations, the first communication interface and the second communication interface are wireless interfaces.

In certain implementations, an RF monitoring system is operatively connected to the RF mitigation system, with the RF monitoring system being configured to monitor a power density of RF radiation within the area of concern and/or RF radiation exposure to the object within the area of concern. The RF mitigation system may be configured, at least in response to the power density of RF radiation within the area of concern and/or the RF radiation exposure to the object within the area of concern exceeding a predetermined threshold, to open the relay to automatically interrupt the power to the RF radiation source.

In other implementations, the RF monitoring system is configured to monitor RF radiation exposure to the object based, at least in part, on an amount of time that the object is within the area of concern, and the RF mitigation system is configured, at least in response to the RF radiation exposure to the object reaching the predetermined threshold, to open the relay to automatically interrupt the power to the RF radiation source.

In various implementations, the RF mitigation system includes a memory configured to store a log of each detected entry of each object into the area of concern. The log may include at least one of a date of entry, a time of entry, a date of exit, a time of exit, and the power density of RF radiation within the area of concern and/or the RF radiation exposure to the object within the area of concern as determined by the RF monitoring system.

In many implementations, the RF mitigation system includes a camera configured to capture an image or video of the object for inclusion in the log.

In certain examples, the RF mitigation system is further configured to display a warning sign at least in response to the power density of RF radiation within the area of concern and/or RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern.

In select examples, the RF mitigation system further includes a sign projector configured to project the warning sign onto a surface in or proximate to the area of concern.

In additional examples, the RF mitigation system further includes a speaker configured to emit an audible warning at least in response to the power density of RF radiation within the area of concern and/or RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern.

In further examples, the RF mitigation system further includes an RF alert light configured to display a color-coded light at least in response to the power density of RF radiation within the area of concern and/or RF radiation exposure to the object within the area of concern exceeding the predetermined threshold.

In still other examples, the RF mitigation system further includes a communication interface configured to send an electronic warning at least in response to the power density of RF radiation within the area of concern and/or RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern. In some implementations, the electronic warning includes one or more of an email, a text message, or a push notification.

In another aspect, a method for mitigating RF radiation exposure includes operatively connecting one or more sensors to an RF mitigation system, the one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source, the RF mitigation system including a processor, an electrical input, an electrical output, and a relay disposed on an electrical path between the electrical input and the electrical output, the relay configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path.

The method also includes operatively connecting the electrical input of the RF mitigation system to a power supply for the RF radiation source. The method further includes operatively connecting the electrical output of the RF mitigation system to the RF radiation source. In addition, the method includes detecting, via the one or more sensors, that the object has entered the area of concern. Moreover, the method includes opening the relay, via the processor, to temporarily interrupt power to the RF radiation source at least in response to detection by the one or more sensors that the object has entered the area of concern.

In yet another aspect, an RF infrastructure sentry system includes one or more sensors configured to detect one or both of an entry or exit of an object into or out of an area of concern proximate to an RF radiation source. The RF infrastructure sentry system also includes an RF mitigation system configured to temporarily disconnect the RF radiation source from a power source while the object is within the area of concern, log, within a memory, one or both of the entry or the exit of the object into or out of the area of concern, and generate at least one of an audible warning or a visual warning to the object that has entered the area of concern.

In some implementations, the RF mitigation system is further configured to send an electronic alert to a remote server concerning the entry or exit of the object into the area of concern.

In additional implementations, the electronic alert includes one or more of an email, a text message, or a push notification.

In certain implementations, the RF mitigation system logs at least one of a date of the entry, a time of the entry, a date of the exit, and a time of the exit.

In various configurations, the RF mitigation system includes a camera configured to capture an image or a video of the object, and wherein the RF mitigation system logs the image or the video within the memory.

In some configurations, the visual warning includes a warning sign projected by a sign projector onto a surface in or proximate to the area of concern.

In certain examples, the sign projector is configured to project an indication of a time remaining to a maximum permissible exposure (MPE) for the object.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying figures are provided by way of illustration and not by way of limitation. The foregoing aspects and other features of the disclosure are explained in the following description, taken in connection with the accompanying example figures relating to one or more embodiments, in which:

FIG. **1** is a schematic diagram of a configuration of an RF infrastructure sentry (RFIS) system;

FIG. **2** is a schematic diagram of another configuration of an RFIS system;

FIG. **3** is a schematic diagram of still another configuration of an RFIS system;

FIG. **4** is a schematic diagram of yet another configuration of an RFIS system;

FIG. **5** is a schematic diagram of an additional configuration of an RFIS system;

FIG. **6** is a schematic diagram of a further configuration of an RFIS system; and

FIG. **7** is a flowchart of a method for mitigating RF radiation exposure proximate to an RF radiation source.

DETAILED DESCRIPTION

In the following description, specific details are set forth in order to provide a thorough understanding of embodiments of the present disclosure. However, it will be apparent that various embodiments may be practiced without these specific details. The figures and description are not intended to be restrictive, but are offered by way of illustration. Various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the disclosure as set forth in the appended claims. Unless otherwise defined, all technical terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs.

FIG. **1** is a schematic diagram of an RF infrastructure sentry (RFIS) system **100** for mitigating RF radiation exposure in proximity to an RF radiation source **102**, such as a cell tower including one or more RF antennas. Other RF radiation sources **102** may include, without limitation, radar facilities, land mobile radio (LMR) facilities, FM/AM/TV broadcast facilities, Project 25 (P25) communication facilities, satellite communication facilities, or the like.

The RFIS system **100** may include one or more sensors **104** configured to detect that an object (such as a human) has entered an area of concern **106** proximate to the RF radiation source **102**, such as a cell tower. The one or more sensors **104** may be located within the area of concern **106**, on a border of the area of concern **106**, and/or outside the area of concern **106**. In some cases, there may be multiple areas of concern **106**, which are not necessarily connected or contiguous.

The one or more sensors **104** may include, for example, an artificial intelligence (AI) camera capable of distinguishing a human from other types of objects that enter the area of concern **106**. Suitable AI cameras may include, for example, an ICAM-540 industrial AI camera available from Advantech Co., Ltd. of Taoyuan City, Taiwan. Other AI cameras may include, for example, the Avigilon line of cameras available from Motorola Solutions Inc., which may include fish eye cameras, double fish eye cameras, bullet cameras, box cameras, dome cameras, panoramic cameras, pan/tilt/zoom (PTZ) cameras, and the like. In some configurations, an AI camera may be capable of identifying and tracking an individual or multiple individuals using facial recognition, movement/gait tracking, or other techniques. The RFIS system **100** may include a variety of other types of sensors **104**, as discussed in greater detail hereafter.

The one or more sensors **104** may be operatively connected (via wired or wireless communication) to an RF mitigation system **108**. As used herein, "operatively connected" may include a connection through one or more intermediaries. The RF mitigation system **108** may include, for example, a processor **110**, a memory **112**, an electrical input **114**, an electrical output **116**, and a power interrupter (such as a relay **118**), disposed on an electrical path **120** between the electrical input **114** and the electrical output **116**. The relay **118** may be embodied, for example, as a solid state relay (SSR) available from XiQu Electric Technology Co., Ltd. of Wenzhou, China, which is capable of handling up to 80 amps at 220 volts.

The one or more sensors **104** may be located remotely from the processor **110**, as shown in FIG. **1**. In other configurations, the one or more sensors **104** (or certain ones of the one or more sensors **104**) may be housed within a component (not shown) including the processor **110**.

In some configurations, the RF mitigation system **108** may further include a communication interface **124**, such as a network interface. The communication interface **124** may implement one or more wired or wireless protocols, non-limiting examples of which include IEEE 802.11x, Wi-Fi, ZigBee, Bluetooth, Bluetooth Low Energy (BLE), Long Range (LoRa) protocol, ESP-Now, Message Queuing Telemetry Transport (MQTT), Global Message Service (GSM), General Packet Radio Service (GPRS), Long Term Evolution (LTE), and/or Z-Wave. In certain implementations, multiple communication interfaces **124** implementing different protocols may be provided for a variety of purposes, such as communicating with sensors **104** or other components of the RFIS system **100**, communicating with a remote server, issuing electronic alerts, or the like.

The processor **110** may be any suitable processing device (e.g., CPU) known in the art. The memory **112** may include, without limitation, one or more random access memories (RAMs), read-only memories (ROMs), electrically erasable programmable read-only memories (EEPROMs), secure digital (SD) cards, solid state drives (SSDs), nonvolatile memory express (NVMe) drives, or the like.

The electrical input **114** of the RF mitigation system **108** may be operatively connected to a power supply **126** for the RF radiation source **102**. The power supply **126** may be an alternating current (AC) or direct current (DC) power supply, depending on the implementation of the RF radiation source **102**. Typically, 5G antennas will use an AC power supply **126**, whereas earlier types of antennas will use a DC power supply **126**. The electrical output **116** of the RF mitigation system **108** may be operatively connected to the usual power and/or powered signal input for the RF radiation source **102**, such that the RF radiation source **102** receives its power (and potentially signal) through the RF mitigation system **108**.

The processor **110** may be operatively connected to the relay **118** and the one or more sensors **104**. In some embodiments, the processor **110** is configured, at least in response to detection by the one or more sensors **104** that an object (or, more specifically, a human) has entered the area of concern **106**, to open the relay **118** to temporarily interrupt power to the RF radiation source **102**. The processor **110** may also be configured to close the relay **118** to automatically restore the power to the RF radiation source **102** at least in response to the one or more sensors **104** detecting that the object has exited the area of concern **106**.

Accordingly, the RF mitigation system **108** may prevent the RF radiation source **102** from emitting harmful radiation while a human is within the area of concern **106**, eliminating the need for permanent signage, which can be unsightly, or barriers, which can be impractical or interfere with network performance.

In some configurations, the power interrupter (e.g., relay **118**) may be replaced by a power reducer, such as a resistor or dynamic attenuator, that reduces power to the RF radiation source **102** to reduce RF exposure/emissions to a predetermined level that is less than, for example, the maximum permissible exposure (MPE). The power reducer may be located on a signal path between an RF source and an RF antenna in certain configurations. In some configurations, the power reducer may be configured to reduce power slowly or by degrees, allowing telephone connections to a cell tower, for example, to switch to a different cell tower without being abruptly disconnected.

In still other configurations, the power interrupter (e.g., relay **118**) may be disposed on the signal path to cut off a signal to the RF radiation source (e.g., RF antenna). In the case of a 5G antenna, the signal path may be optical fiber, and the relay **118** may be an optical relay.

In certain implementations, the processor **110** may be configured to open the relay **118** after a predetermined or calculated time delay, since RF radiation exposure is dependent upon the time that a human is in the area of concern **106**. The delay may be based, for example, on the signal strength of the RF radiation source **102**, the power density of RF radiation within the area of concern **106**, the accumulated RF radiation exposure of a human within the area of concern **106**, or in other ways.

In certain implementations, the communication interface **124** may be configured to send a message to a network operations center (NOC), which supplies an RF signal to the RF radiation source **102**. The message may be embodied in any suitable format, such as a short message service (SMS) message, Web Services Notification (WSN), push notification, Transmission Control Protocol/IP Protocol (TCP/IP) packet, a User Datagram Protocol (UDP) packet. The message may instruct (or request) the NOC to interrupt or reduce the RF signal before it is sent to the RF radiation source **102**. The message may be automatically processed by an Application Programming Interface (API) running on a software service for the NOC. Alternatively, the message may be sent to a human operator at the NOC requesting manual intervention. The communication interface **124** may be used to interrupt (or reduce) power to the RF radiation source **102** as an alternative, or in addition, to the relay **118**. For example, if the NOC does not respond within a predetermined time period, the relay **118** may be used to interrupt power to the RF radiation source **102**.

FIG. **1** illustrates a configuration in which the power supplied by the output **116** of the RF mitigation system **108** to the RF radiation source **102** has not yet been combined with an RF signal to be transmitted. Subsequently, an RF source **122** may combine the RF signal (provided, for example, by a NOC) with the power flowing from the output **116** before it is supplied to the RF radiation source **102** (e.g., RF antenna). The RF mitigation system **108** is considered to be operatively connected to the RF radiation source **102** (via the RF source **122**) in this configuration.

FIG. **2** illustrates another configuration of an RFIS system **200**, where the RF source **122** is disposed between the power supply **126** and the input **114** of the RF mitigation system **108**. The RF source **122** combines the power from the power supply **126** with the RF signal (provided, for example, by the NOC). In this embodiment, the relay **118** interrupts the powered RF signal before it is provided to the RF radiation source **102** (e.g., RF antenna). In this configuration, the input **114** of the RF mitigation system **108** is considered to be operatively connected to the power supply **126** (via the RF source **102**). The remainder of this disclosure will not specify whether the RF signal is added to the power before or after the RF mitigation system **108**, and the configurations disclosed herein should be construed to include either arrangement.

FIG. **2** also illustrates a configuration where the one or more sensors **104** include a standard digital camera that is not capable of distinguishing humans from other objects. In this implementation, the communication interface **124** may communicate through a network **202**, such as, without limitation, a local area network (LAN), a wide area network (WAN), a cellular network, and/or the Internet, with a machine learning (ML) system **204** operating on a remote server. The ML system **204** may include, for example, a neural network, such as a convolutional neural network (CNN) or feedforward neural network (FNN), that has been trained for distinguishing humans from other objects. The processor **110** may send images or video from the digital camera to the ML system **204** via the communication interface **124** and the network **202** and receive therefrom an indication (e.g., binary or probability) of whether the object is a human. Based on the indication, the processor **110** will determine whether to open the relay **118**. In some implementations, the processor **110** will open the relay **118** if the ML system **204** (or a similarly configured AI camera as in FIG. **1**) reports that the probability of the object being a human is beyond a specified confidence threshold (e.g., 90%). In certain embodiments, whether the processor **110** opens the relay **118** may depend on the RF conditions at the time (e.g., the power density of RF radiation within the area of concern **106** and/or the RF radiation exposure to the object within the area of concern **106**), as described in greater detail below.

In some configurations, as illustrated in FIG. **3**, an RFIS system **300** may include one or more of a variety of sensors **104**, such as, without limitation, a motion detector **302** (e.g., IR, ultrasonic, microwave), a proximity detector **304**, a barrier tip/move sensor **306**, a photoelectric beam sensor **308**, a breakaway wire sensor **310**, a time-of-flight (TOF) distance sensor **312**, and the like. Implementations of barrier tip/move sensor **306** are described in U.S. Pat. No. 10,969,415, for RF RADIATION SOURCE SECTOR MONITORING DEVICE AND METHOD, which is incorporated herein by reference.

In some implementations, one or more of the foregoing sensors **104** may operate in concert with a camera or an AI camera with human-detection capabilities. For example, an object may be detected by a photoelectric beam sensor **308**, which is installed outside of the field of view of the camera. Detection of the object by the photoelectric beam sensor **308** may cause the processor **110** to take a first set of actions, such as, for example, issuing a visual or audible warning or digitally projecting a sign, as described in greater detail hereafter. Later, if the object is confirmed to be a human by an AI camera or the like, the processor **110** may perform a second set of actions, such as opening the relay **118**, as previously described, or logging the entry, as detailed hereafter. A wide variety of actions may be specified for the processor **110** in response to distinct types of sensor input based on programmed instructions stored in the memory **112** and/or provided via the communication interface **124**.

FIG. **4** illustrates an RFIS system **400** in which the functionality of the RF mitigation system **108** is divided between a control unit **402** and a relay unit **404**. The control unit **402** may include, for example, the processor **110**, the memory **112**, and the communication interface **124**, while the relay unit **404** may include the electrical input **114**, the electrical output **116**, the relay **118**, and the electrical path **120**. This configuration allows for convenient placement of the control unit **402** and the relay unit **404** at any suitable location on or near the RF radiation source **102** and, in some cases, the power supply **126**. In addition, this configuration may allow for multiple relay units **404**, each of which may serve a different RF radiation source **102** within a single RFIS system **400**.

In some implementations, the relay unit **404** includes a communication interface **124** operatively connected to the communication interface **124** of the control unit **402** via a wired or wireless connection. The processor **110**, upon receiving an indication that the one or more sensors **104** have detected an object (or in some configurations, a human) entering the area of concern **106**, may send an instruction via the communication interfaces **124** and a wireless connection **406** to open the relay **118** within the relay unit **404**. Alternatively, the communication interfaces **124** may use a wired connection. In other configurations, the processor **110** may include a direct (e.g., wired) connection **408** to the relay **118** that does not require the communication interfaces **124**.

FIG. **5** illustrates an RFIS system **500** in which the control unit **402** includes or is operatively connected with an RF monitor **502** configured to monitor the signal strength of the RF radiation source **102**, the power density of RF radiation within the area of concern and/or RF radiation exposure to the object in the area of concern **106**. RF radiation exposure may be determined by a variety of factors, including signal strength, signal frequency, and time of exposure. Thus, the RF monitor **502** may be configured, in some embodiments, to estimate the RF radiation exposure to a human that has entered the area of concern **106**, which will increase over time as long as the human is within the area of concern **106**.

An example of RF monitor **502** is described in U.S. Pat. No. 10,969,415, for RF RADIATION SOURCE SECTOR MONITORING DEVICE AND METHOD, which is incorporated herein by reference. The RF monitor **502** may have, for example, a scanning bandwidth of 5 MHz with sampling rates between 4.3 us to 2.86 μs and an RF detection threshold of −90 dBm.

In some implementations, the RF monitor **502** may include a RF meter that can measure the power of an entire frequency range from, for example, 600 MHz to 70 GHz, including all carrier waves, harmonics, and intermodulation products. In other configurations, the RF monitor **502** may monitor signal strength for discrete frequency bands. Certain bands are more hazardous to humans at high power levels than others. For example, the frequency range of 30-300 MHz, where whole-body absorption of RF energy by human beings is most efficient, is of particular concern. At other frequencies whole-body absorption is less efficient, and, consequently, may be less of a concern for purposes of interrupting power to the RF radiation source **102** when a human is detected.

In still other configurations, the RF monitor **502** will determine RF radiation exposure within the area of concern **106** for a human, generally, or for one or more specific humans that have entered area of concern **106**. The OET Bulletin **65** of the FCC provides guidelines for human exposure to radiofrequency electromagnetic fields. Maximum permissible exposure (MPE) limits are defined in terms of power density (units of milliwatts per centimeter squared: mW/cm^2), electric field strength (units of volts per meter: V/m) and magnetic field strength (units of amperes per meter: A/m). In the far-field of a transmitting antenna, where the electric field vector (E), the magnetic field vector (H), and the direction of propagation can be considered to be all mutually orthogonal ("plane-wave" conditions), these quantities are related by the following equation:

$$S = \frac{E^2}{3770} = 37.7\ H^2 \qquad \text{Eq. 1}$$

where S=power density (mW/cm^2), E=electrical field strength (V/m), and H=magnetic field strength (A/m).

An aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the whole body averaged specific absorption rate (SAR) that will result from the exposure and the MPEs specified in the OET Bulletin **65**. A whole-body average SAR of 0.4 W/kg has been specified as the restriction that provides adequate protection for occupational exposure. Local values of exposures that exceed the stated MPEs may not be related to non-compliance if the spatial average of RF fields over the body does not exceed the MPEs. Another feature of the exposure guidelines is that exposures, in terms of power density, E^2 or H^2, may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure.

As an illustration of the application of time-averaging to occupational/controlled exposure consider the following. The relevant interval for time-averaging for occupational/controlled exposures is six minutes. This means, for example, that during any given six-minute period a worker could be exposed to two times the applicable power density limit for three minutes as long as he or she were not exposed at all for the preceding or following three minutes. Similarly, a worker could be exposed at three times the limit for two minutes as long as no exposure occurs during the preceding or subsequent four minutes, and so forth.

This concept can be generalized by considering Equation (2) that allows calculation of the allowable time(s) for exposure at [a] given power density level(s) during the appropriate time-averaging interval to meet the exposure criteria of the OET Bulletin **65**. The sum of the products of the exposure levels and the allowed times for exposure must equal the product of the appropriate MPE limit and the appropriate time-averaging interval.

$$\Sigma S_{exp}\, t_{exp} = S_{limit} t_{avg} \qquad \text{Eq. 2}$$

where S_{exp}=power density level of exposure (mW/cm^2), S_{limit}=appropriate power density MPE limit (mW/cm^2) (e.g., as specified in OET Bulletin **65**), t_{exp}=allowable time of exposure for S_{exp}, and t_{avg}=appropriate MPE averaging time.

The RF monitor **502** may output an indication of the power density of RF radiation with the area of concern and/or calculated RF radiation exposure within the area of concern **106** to the processor **110**. In some embodiments, the RF monitor **502** is capable of tracking individual RF radiation exposure for one or more humans (individually identified, for example, by an AI camera) based on the length of time each human is within the area of concern **106**. In other embodiments, a determination is made for radiation exposure to the object (based, for example, on power density levels) that has been detected in the area of concern **106**.

As the RF monitor **502** may be positioned in a location outside of the area of concern, it may need to be calibrated via, for example, time-synchronized measurements between, for example, power density measured at the RF monitor **502** and power density at one or more given locations within the area of concern **106**. For example, if the power density is at the RF monitor **502** is X, the power density at a given location within the area of concern **106** may be X*Y. Based on the time-synchronized measurements, a 3D variation map between the measured power density at the RF monitor and a volume within the area of concern **106** may be calculated, allowing for the power density at any given location within the area of concern **106** to be calculated or estimated, which may change as the object (e.g., human) moves. An overall RF radiation exposure for the object after entering the area of concern **106** may then be calculated over time.

In some implementations, the processor **110** will cause the relay **118** to open if (1) the one or more sensors **104** have detect that an object (e.g., human) has entered the area of concern **106**, and (2) power density of RF radiation within the area of concern and/or the RF radiation exposure to the object within the area of concern has exceeded the predetermined threshold (e.g., MPE) based, for example, on the signal frequency, power density, time of exposure, and the like. In other words, the processor **110** need not open the relay **118** simply in response to the object being detected if the power density of the RF radiation source **102** or the RF radiation exposure for the object is below the predetermined threshold. As described in greater detail hereafter, the power density of the RF radiation and/or the RF radiation exposure, as reported by the RF monitor **502**, may be used to determine whether to issue various warnings (e.g., visual or audible) or electronic alerts and/or to take other action, such as logging the entry of the object into the area of concern **106**.

In some implementations, the memory **112** of the control unit **402** may be used to store a log **504** of certain events, such as the entry of the object (or human) into the area of concern **106**. This may include, without limitation, the date of entry (i.e., the date the object entered the area of concern **106**), the time of entry, the RF radiation conditions (e.g., signal strength, power density, and/or RF radiation exposure at the time of entry as reported by the RF monitor **502**), a photograph (or video) of the object entering the area of concern **106** (if the one or more sensors **104** include a camera). In some configurations, video might not be captured for privacy reasons. The log **504** may be further used to store the date that the object exited the area of concern **106**, the time of exit, a photograph (or video) of the object exiting the area of concern **106**, who was notified of the entry (as well as when and how the notification took place), what alerts (visual or audible) were generated, and/or the like. The log **504** may be used in reviewing an incident of unauthorized entry into area of concern **106**, in preparing a report to or responding to an audit by regulatory authorities, or the like.

In some configurations, events are stored in the log **504** only if the object is determined to be a human and/or only if the RF monitor **502** reports a signal strength or an RF radiation exposure for the object that is greater than the predetermined threshold. This may prevent, for example, non-human objects such as animals, being logged when entering the area of concern **106**. In some implementations, however, every object that enters the area of concern **106** may be logged, but certain actions may not be taken unless the object is determined to be a human, such as opening the relay **118**, issuing certain alerts, and/or the like.

In various configurations, when the entry of an object is detected in the area of concern **106** (and, in some implementations, if the signal strength of the RF radiation source **102** and/or the RF radiation exposure for the object within the area of concern **106** exceeds a predetermined threshold) the processor **110** may send an electronic alert **506** via the communication interface **124** and the network **202** to a remote server **508**. The electronic alert **506** may be embodied in any suitable format, such as a text message using, e.g., the Short Message Service (SMS), the Rapid Message Service (RMS), or the Rich Communication Service (RCS), an email messages using, e.g., the Simple Mail Transfer Protocol (SMTP), the Internet Message Access Protocol (IMAP), and/or the Post Office Protocol (POP), a push notification using, e.g., the Push Protocol, a Web Services Notification (WSN) or any of a number of packets, such as, without limitation, TCP/IP packets, UDP packets, or Internet Group Management Protocol (IGMP) packets. The electronic alert **506** may include any of the information stored in the log **504** related to a current event involving entry of a particular object into the area of concern **106**. In some configurations, the processor **110** may send the log **504** to the remote server **508**, either periodically or on demand, for reporting or auditing purposes.

The remote server **508** may then forward the electronic alert **506** (or generate one or more new electronic alerts in the form of an email **510**, a text message **512**, and/or a push notification **514**) to a user device, non-limiting examples of which may include a computer terminal **516** or a smartphone **518**. Logs **504** may also be sent via the remote server **508** to the user device in a similar fashion. The email **510**, text message **512**, and/or push notification **514** may be sent using any suitable protocol or network infrastructure as known to those of skill in the art.

In some embodiments, the user may send a command **520** via the remote server **508** and/or user devices (e.g., the computer terminal **516** or the smartphone **518**) to the control unit **402**. For example, after reviewing a photograph (or video) of the object entering area of concern **106**, the user may determine that the object is not a human, whether or not it is recognized as such by, for example, an AI camera. In such a case, the user may send an "override" command **520** to cause the processor **110** to close the relay **118** and restore the power to the RF radiation source **102** if such were temporarily interrupted. In some embodiments, override commands may not be facilitated, however, for security reasons. Furthermore, in some configurations, the control unit **402** only initiates communication with the remote server **508**, but does not receive incoming communications.

The user may send other commands **520** that may control how the processor **110** responds to different types of input from the one or more sensors **104**, e.g., the predetermined threshold for power density or RF radiation exposure needed to interrupt power to the RF radiation source **102** if an object (or human) breaches the area of concern **106**, whether (and under what circumstances) to present audible or visual warnings (as described in greater detail hereafter), how often the processor **110** sends updates (e.g., log **504**), and/or whether (and under what conductions) to send electronic alerts **506** and to whom and with what parameters.

FIG. **6** illustrates a configuration of an RFIS system **600** in which the RF monitor **502** and RF mitigation system **108** are embodied as separate components. In addition, the processor **110** may be operatively connected (via a wired or wireless connection) to one or more warning devices, such as, for example, a warning sign projector **602**, a warning sound emitter **604**, and a warning light **606**. The one or more warning devices may be activated, for example, if a human enters the area of concern **106** when the signal strength of the RF radiation source (or RF radiation exposure to the object within the area of concern **106**) exceeds a predetermined threshold.

The warning sign projector **602** may be embodied as a digital sign projector that projects a warning sign onto a surface in or in proximity to the area of concern **106**. The warning sign projector **602** may use lasers or high-contrast and high-intensity light emitting diodes (LEDs) for projection. A suitable warning sign projector **602** may include, for example, a SAFETYCAST™ 300 Sign Projector available from Laserglow Technologies Industrial Safety of Toronto, Ontario, Canada. The surface onto which the warning sign is projected may include the floor, a wall, HVAC equipment or other machinery, the RF radiation source **102**, itself, and/or the like.

In some implementations, the warning sign may indicate a telephone number or other contact information for an operator of the RF radiation source **102**. In certain implementations, the warning sign may include dynamic information, such as a countdown, which may serve as an indication to a worker of the amount of time remaining until the maximum permitted exposure (MPE).

The warning sound emitter **604** may include a loudspeaker, i.e., an electroacoustic transducer that converts an electrical audio signal into a corresponding sound. The warning sound emitter **604** may be an electronic siren, which incorporate circuits such as oscillators, modulators, and amplifiers to synthesize a selected siren tone (wail, yelp, pierce/priority/phaser, hi-lo, scan, airhorn, etc.), which is played through external speakers. Alternatively, the warning sound emitter **604** may utilize sampled audio (such as spoken words) and/or text-to-speech technology to verbally warn a person of the danger of RF radiation within the area of concern **106**. In still other configurations, the warning sound emitter **604** may be a pneumatic siren (e.g., aerophone).

The warning light **606** may include one or more light-emitting devices, such as LEDs, which may be color-coded to indicate whether the area of concern **106** is safe or unsafe. For example, the warning light **606** may include a red LED to indicate that the area of concern **106** is currently unsafe because the signal strength of the RF radiation source **102** (or the RF radiation exposure within the area of concern **106**) exceeds a predetermined threshold. In some embodiments, the warning light **606** may include LEDs of multiple colors. For example, a green LED may be included to indicate that the area of concern **106** is currently safe. An orange or yellow LED may be used to indicate that the area of concern **106** is safe for exposures shorter than a predetermined time period.

Multiple warning devices may be used simultaneously, including the warning sign projector **602**, the warning sound emitter **604**, and the warning light **606**. The processor **110** may be programmed via instructions in the memory and/or by commands sent via the communication interface **124**, which may include the threshold signal strength (or RF radiation exposure) to trigger a warning, which device(s) should be used in connection with a warning, etc.

FIG. **7** is a flowchart of a method **700** for mitigating RF radiation exposure. At step **702**, the method **700** may include operatively connecting one or more sensors to an RF mitigation system, the one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source. The RF mitigation system may include a processor, an electrical input, an electrical output, and a relay disposed on an electrical path between the electrical input and the electrical output. The relay may be configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path.

At step **704**, the method **700** may also include operatively connecting the electrical input of the RF mitigation system to a power supply for the RF radiation source. At step **706**, the method **700** may further include operatively connecting the electrical output of the RF mitigation system to the RF radiation source.

At step **708**, the method **700** may additionally include detecting, via the one or more sensors, that the object has entered the area of concern. At step **710**, the method **700** may also include opening the relay, via the processor, to temporarily interrupt power to the RF radiation source at least in response to detection by the one or more sensors that the object has entered the area of concern.

The systems and methods described herein can be implemented in hardware, software, firmware, or combinations of hardware, software and/or firmware. In some examples, systems described in this specification may be implemented using a non-transitory computer readable medium storing computer executable instructions (e.g., program code) that when executed by one or more processors of a computer cause the computer to perform operations. Computer-readable media suitable for implementing the control systems described in this specification include non-transitory computer-readable media, such as disk memory devices, chip memory devices, programmable logic devices, random access memory (RAM), read only memory (ROM), optical read/write memory, cache memory, magnetic read/write memory, flash memory, and application-specific integrated circuits. In addition, a computer readable medium that implements a control system described in this specification may be located on a single device or computing platform or may be distributed across multiple devices or computing platforms.

One skilled in the art will readily appreciate that the present disclosure is adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. Changes and other uses will occur to those skilled in the art which are encompassed within the spirit of the present disclosure as defined by the scope of the claims.

No admission is made that any reference, including any non-patent or patent document cited in this specification, constitutes prior art. In particular, it will be understood that, unless otherwise stated, reference to any document herein does not constitute an admission that any of these documents forms part of the common general knowledge in the art in the United States or in any other country. Any discussion of the references states what their authors assert, and the applicant reserves the right to challenge the accuracy and pertinence of any of the documents cited herein. All references cited herein are fully incorporated by reference, unless explicitly indicated otherwise. The present disclosure shall control in the event there are any disparities between any definitions and/or description found in the cited references.

What is claimed is:

1. An RF infrastructure sentry system comprising:

a processor;

one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source, wherein the one or more sensors includes a camera, and wherein the object is a human; and

an RF mitigation system operatively connected to the one or more sensors, the RF mitigation system comprising:

a communication interface operatively connected to the camera and configured to transmit images or video captured by the camera to a machine learning system configured to distinguish the human from other types of objects;

an electrical input operatively connected to a power supply for the RF radiation source;

an electrical output operatively connected to the RF radiation source; and

a relay disposed on an electrical path between the electrical input and the electrical output and configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path; and

an RF monitoring system operatively connected to the RF mitigation system, the RF monitoring system configured to monitor a power density of RF radiation within the area of concern or an RF radiation exposure to the object within the area of concern for a predetermined amount of time,

wherein the RF mitigation system is configured, at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding a predetermined threshold for the predetermined amount of time, to open the relay to automatically interrupt power to the RF radiation source.

2. The RF infrastructure sentry system of claim **1**, wherein the area of concern is a region proximate to the RF radiation source where the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeds the predetermined threshold when the RF radiation source is in operation.

3. The RF infrastructure sentry system of claim **1**, wherein the one or more sensors further include an artificial intelligence (AI) camera configured to distinguish the human from other types of objects.

4. The RF infrastructure sentry system of claim **1**, wherein the machine learning system includes a trained neural network.

5. The RF infrastructure sentry system of claim **1**, wherein the one or more sensors further include at least one of a proximity sensor, a motion detector, a barrier tip/move sensor, or a photoelectric beam sensor.

6. The RF infrastructure sentry system of claim **1**, wherein the processor is further configured to close the relay to automatically restore the power to the RF radiation source at least in response to the one or more sensors detecting that the object has exited the area of concern.

7. The RF infrastructure sentry system of claim **1**, wherein the electrical input, the electrical output, and the relay are components of a relay unit disposed remotely from a control unit including the processor.

8. The RF infrastructure sentry system of claim **7**, wherein the control unit includes a first communication interface configured to communicate with a second communication interface included in the relay unit, wherein the second communication interface is operatively connected to the relay.

9. The RF infrastructure sentry system of claim **8**, wherein the first communication interface and the second communication interface are wireless interfaces.

10. The RF infrastructure sentry system of claim **1**, wherein the RF mitigation system includes a memory configured to store a log of each detected entry of each object into the area of concern.

11. The RF infrastructure sentry system of claim **10**, wherein the log includes at least one of a date of entry, a time of entry, date of exit, the time of exit, and the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern as determined by the RF monitoring system.

12. The RF infrastructure sentry system of claim **10**, wherein the RF mitigation system includes a camera configured to capture an image or video of the object for inclusion in the log.

13. The RF infrastructure sentry system of claim **1**, wherein the RF mitigation system is further configured to display a warning sign at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern.

14. The RF infrastructure sentry system of claim **13**, wherein the RF mitigation system further includes a sign projector configured to project the warning sign onto a surface in or proximate to the area of concern.

15. The RF infrastructure sentry system of claim **14**, wherein the sign projector is configured to project an indication of a time remaining to a maximum permissible exposure (MPE) for the object.

16. The RF infrastructure sentry system of claim **1**, wherein the RF mitigation system further includes a speaker configured to emit an audible warning at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern.

17. The RF infrastructure sentry system of claim **1**, wherein the RF mitigation system further includes an RF alert light configured to display a color-coded light at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding the predetermined threshold.

18. The RF infrastructure sentry system of claim **1**, wherein the RF mitigation system further includes a communication interface is configured to send an electronic alert at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding the predetermined threshold when the one or more sensors detect that the object has entered the area of concern.

19. The RF infrastructure sentry system of claim **18**, wherein the electronic alert includes one or more of an email, a text message, or a push notification.

20. An RF infrastructure sentry system comprising:
- a processor;
- one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source;
- an RF mitigation system operatively connected to the one or more sensors, the RF mitigation system comprising:
  - an electrical input operatively connected to a power supply for the RF radiation source;
  - an electrical output operatively connected to the RF radiation source;
  - a relay disposed on an electrical path between the electrical input and the electrical output and configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path; and
  - a sign projector configured to project a warning sign onto a surface in or proximate to the area of concern, wherein the sign projector is configured to project an indication of a time remaining to a maximum permissible exposure (MPE) for the object; and
- an RF monitoring system operatively connected to the RF mitigation system, the RF monitoring system configured to monitor a power density of RF radiation within the area of concern or an RF radiation exposure to the object within the area of concern for a predetermined amount of time,
- wherein the RF mitigation system is configured, at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding a predetermined threshold for the predetermined amount of time, to open the relay to automatically interrupt power to the RF radiation source.

21. An RF infrastructure sentry system comprising:
- one or more sensors configured to detect that an object has entered an area of concern proximate to an RF radiation source, wherein the one or more sensors includes a camera, and wherein the object is a human;
- an RF mitigation system operatively connected to the one or more sensors, the RF mitigation system comprising:
  - a communication interface operatively connected to the camera and configured to transmit images or video captured by the camera to a machine learning system configured to distinguish the human from other types of objects;
  - an electrical input operatively connected to a power supply for the RF radiation source;
  - an electrical output operatively connected to the RF radiation source;
  - a relay disposed on an electrical path between the electrical input and the electrical output and configured to selectively connect or disconnect the electrical input and the electrical output through the electrical path;
  - a sign projector configured to project a warning sign onto a surface in or proximate to the area of concern, wherein the sign projector is configured to project an indication of a time remaining to a maximum permissible exposure (MPE) for the object; and
  - a processor operatively connected to the relay and configured, at least in response to detection by the

one or more sensors that the object has entered the area of concern, to open the relay to temporarily interrupt power to the RF radiation source; and

an RF monitoring system operatively connected to the RF mitigation system, the RF monitoring system configured to monitor a power density of RF radiation within the area of concern or an RF radiation exposure to the object within the area of concern,

wherein the RF mitigation system is configured, at least in response to the power density of the RF radiation within the area of concern or the RF radiation exposure to the object within the area of concern exceeding a predetermined threshold, to open the relay to automatically interrupt the power to the RF radiation source.

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