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(54) **ROBOTIC APPARATUS FOR VEHICLE OCCUPANT PROTECTION**

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See application file for complete search history.

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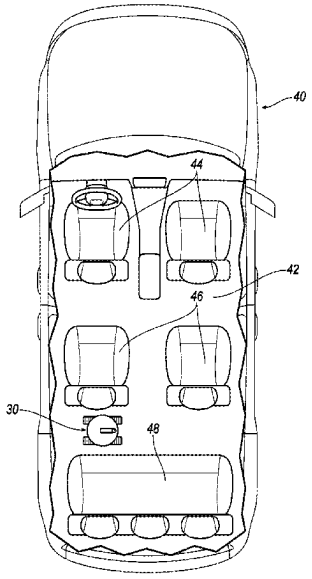
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(57) **ABSTRACT**

An apparatus includes a robot body, at least one sensor coupled to the robot body and positioned to receive stimuli from a passenger cabin of a vehicle, an actuatable component coupled to the robot body, and a computer coupled to the robot body and communicatively coupled to the sensor and the actuatable component. The computer is programmed to predict an imminent anomalous event in the vehicle based on data from the at least one sensor, and in response to the determination, actuate the actuatable component to remediate the anomalous event.

20 Claims, 5 Drawing Sheets



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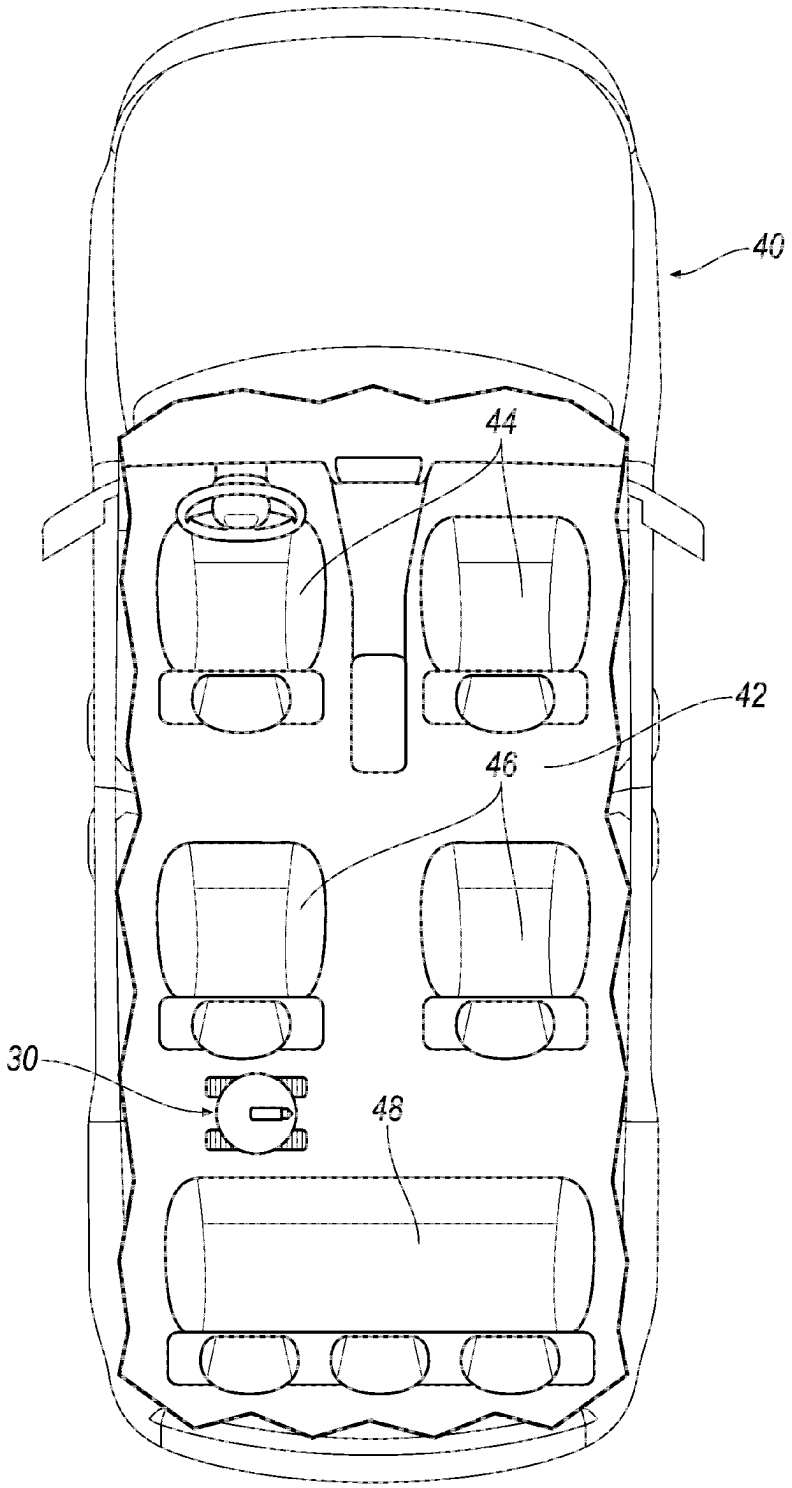


FIG. 1

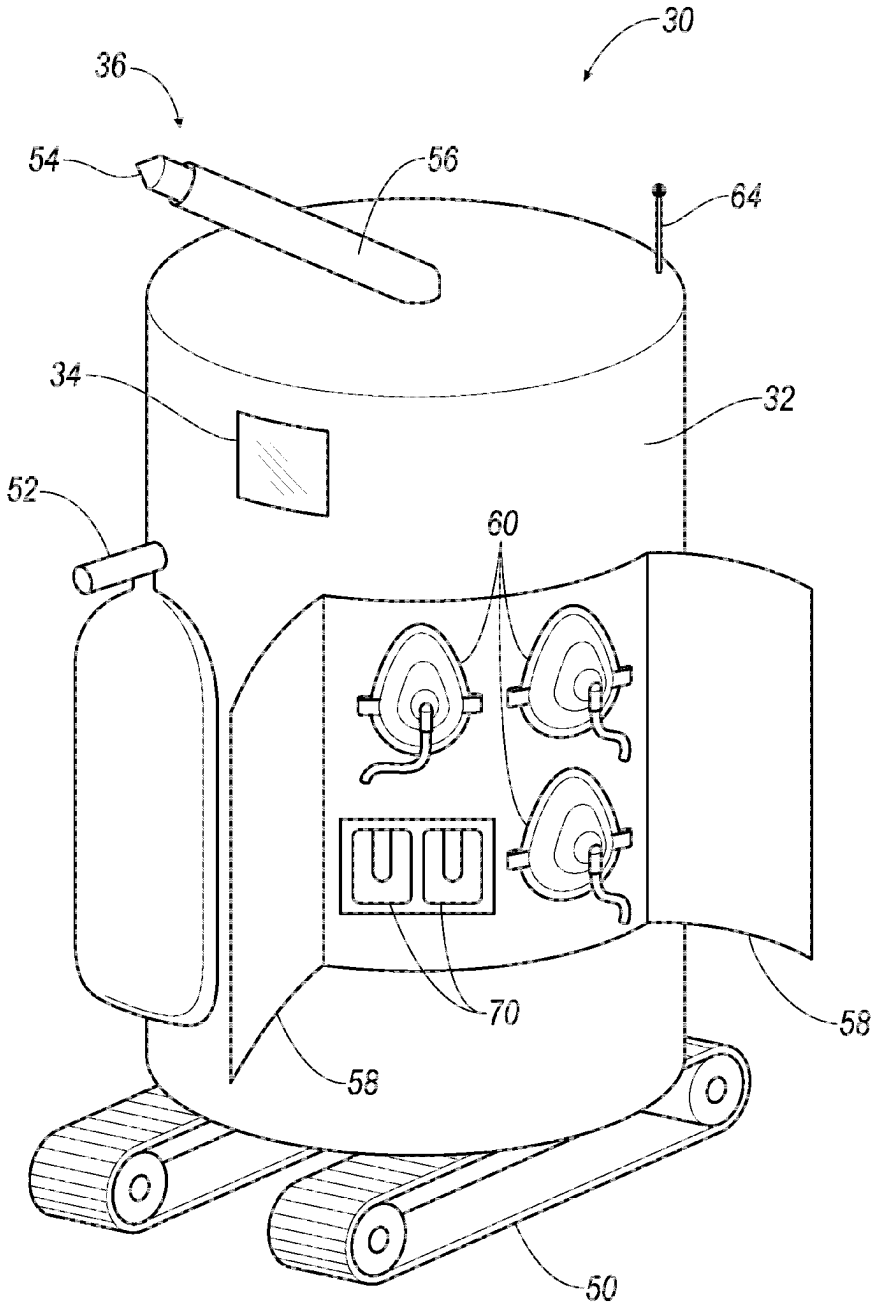


FIG. 2

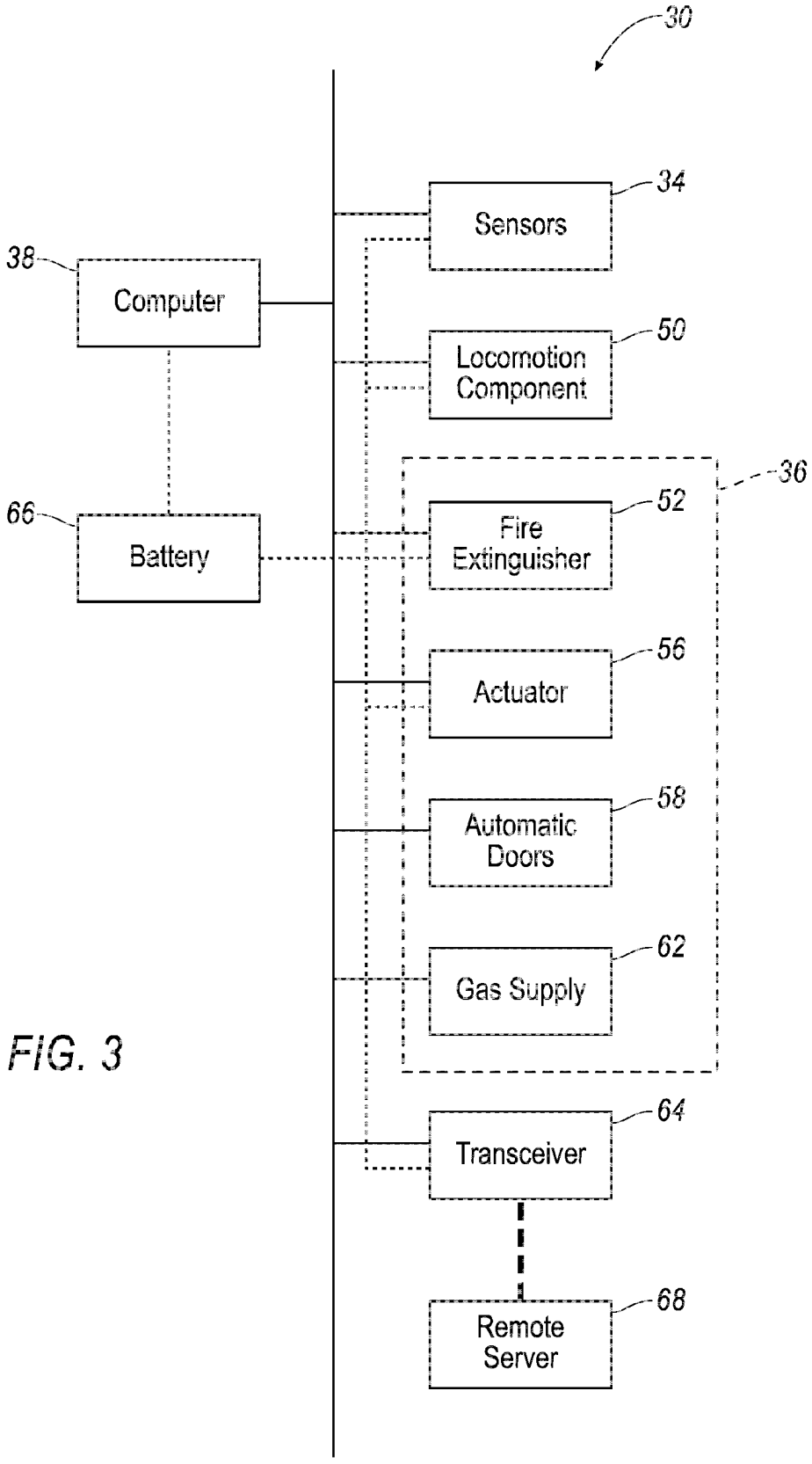

30
34
Sensors
38
Computer
50
Locomotion Component
36
66
Battery
52
Fire Extinguisher
56
Actuator
58
Automatic Doors
62
Gas Supply
64
Transceiver
68
Remote Server

FIG. 3

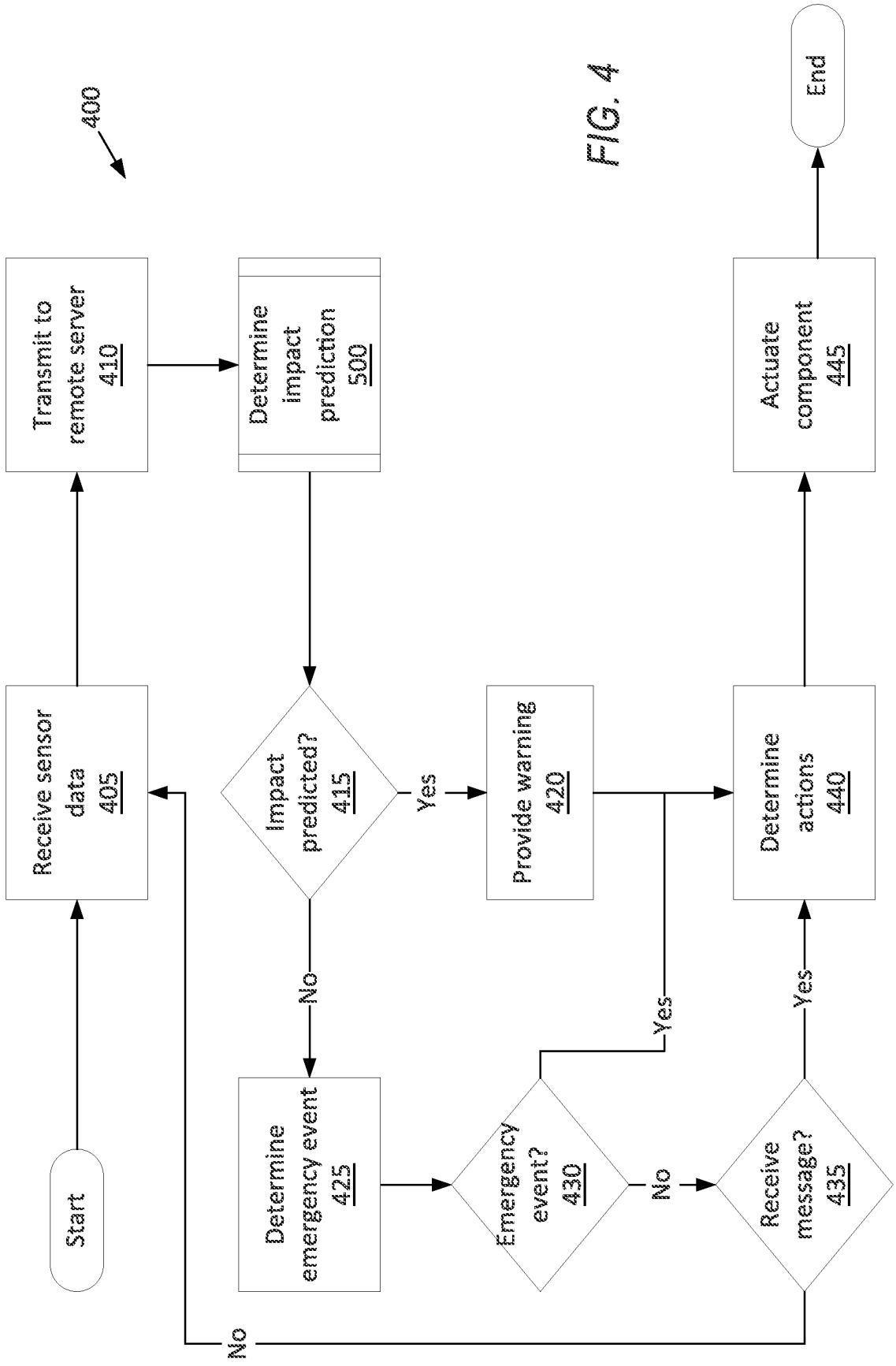

400
Start
Receive sensor data 405
Transmit to remote server 410
Determine impact prediction 500
Impact predicted? 415
Yes
No
Provide warning 420
Determine emergency event 425
Emergency event? 430
Yes
No
Receive message? 435
Yes
No
Determine actions 440
Actuate component 445
End

FIG. 4

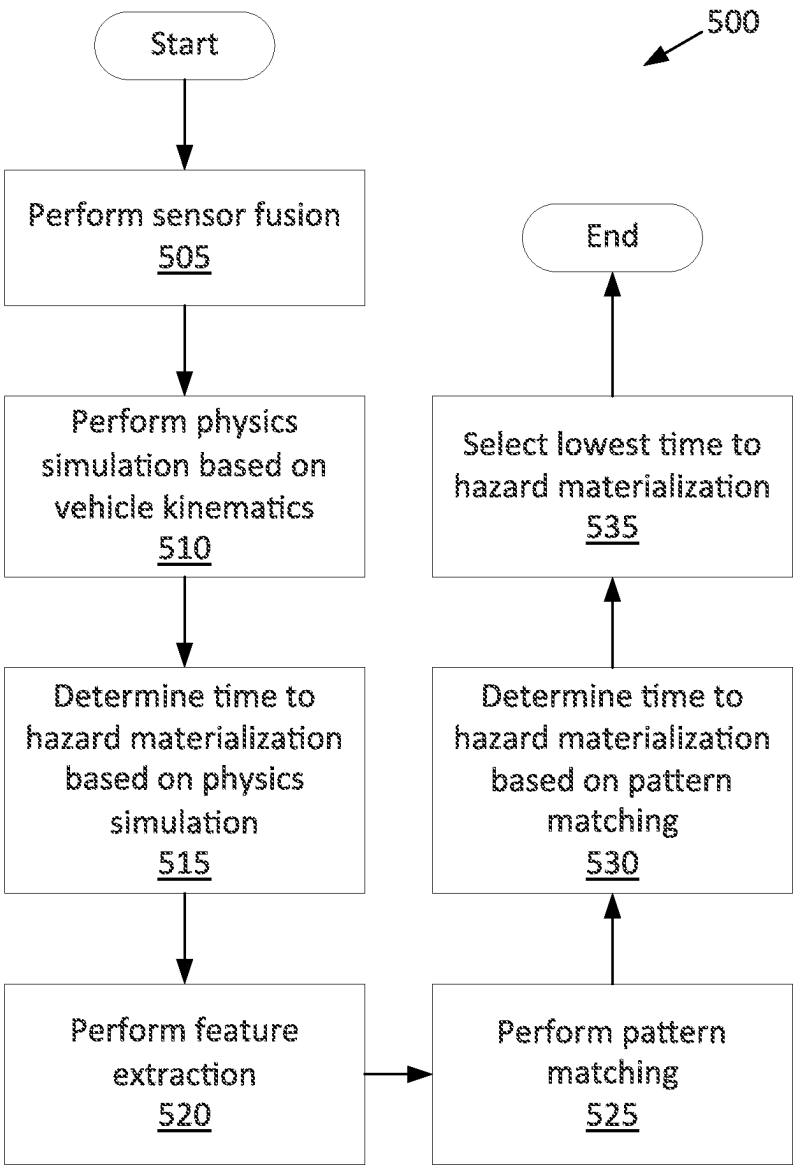

500
Start
Perform sensor fusion
505
Perform physics simulation based on vehicle kinematics
510
Determine time to hazard materialization based on physics simulation
515
Perform feature extraction
520
Perform pattern matching
525
Determine time to hazard materialization based on pattern matching
530
Select lowest time to hazard materialization
535
End

FIG. 5

ROBOTIC APPARATUS FOR VEHICLE OCCUPANT PROTECTION

BACKGROUND

Vehicles are typically equipped with impact sensors, which are adapted to detect an impact to the vehicle. Types of impact sensors include post-contact sensors such as linear or angular accelerometers, gyroscopes, pressure sensors, and contact switches; and pre-impact sensors such as radar, lidar, and vision-sensing systems. The vision systems can include one or more cameras, CCD image sensors, CMOS image sensors, etc. Impact sensors are attached to a vehicle at numerous points in or on the vehicle. Other components of a vehicle can be triggered by a signal from an impact sensor, including airbags, seatbelt pretensioners, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of an example vehicle with a passenger cabin exposed for illustration.

FIG. **2** is a perspective view of a robotic apparatus disposed in the passenger cabin.

FIG. **3** is a block diagram of the robotic apparatus.

FIG. **4** is a process flow diagram of an example process for operating the robotic apparatus in response to an anomalous event.

FIG. **5** is a process flow diagram of an example process for predicting an impact to the vehicle.

DETAILED DESCRIPTION

An apparatus includes a robot body, at least one sensor coupled to the robot body and positioned to receive stimuli from a passenger cabin of a vehicle, an actuatable component coupled to the robot body, and a computer coupled to the robot body and communicatively coupled to the sensor and the actuatable component. The computer is programmed to predict an imminent anomalous event in the vehicle based on data from the at least one sensor, and in response to the prediction, actuate the actuatable component to remediate the anomalous event.

Remediating the anomalous event may include providing an exit for occupants from the passenger cabin.

Remediating the anomalous event may include extinguishing a fire.

The apparatus may be unattached to the vehicle.

The apparatus may further include a locomotion component coupled to the robot body. The locomotion component may include at least one of wheels, tracks, or legs.

The actuatable component may include a fire extinguisher.

The actuatable component may include an actuator and a striker movable by the actuator relative to the robot body, and the actuator may be equipped to move the striker at a sufficiently high speed relative to the robot body to break tempered glass.

The apparatus may further include a plurality of breathing masks detachably attached to the robot body.

The at least one sensor may include a temperature sensor.

The at least one sensor may include a smoke detector.

The apparatus may further include a transceiver coupled to the robot body and communicatively coupled to the computer, and the at least one sensor may include a camera, and the computer may be further programmed to instruct the transceiver to transmit data received from the camera to a remote server. The computer may be further programmed to instruct the transceiver to transmit the data received from the camera to the remote server in real time.

The computer may be further programmed to, in response to a message from the remote server, actuate the actuatable component to provide an exit for occupants from the passenger cabin or to extinguish a fire.

The apparatus may further include a battery coupled to the robot body and electrically coupled to the computer, the at least one sensor, and the actuatable component.

A computer includes a processor and a memory storing instructions executable by the processor to predict an imminent anomalous event in the vehicle based on data received from at least one sensor mounted to an apparatus in a passenger cabin of the vehicle, wherein the apparatus is unattached to the vehicle; and in response to the prediction, actuate an actuatable component of the apparatus to remediate the anomalous event.

An apparatus includes a robot body; means for moving the robot body around inside a passenger cabin of a vehicle; means, mounted to the robot body, for predicting an imminent anomalous event in the vehicle; means, mounted to the robot body, for remediating the anomalous event; and a computer programmed to, upon predicting the imminent anomalous event, activate the means for remediating the anomalous event.

The apparatus may further include means for protecting occupants of the passenger cabin from smoke.

The means for moving the robot body around may be independent of the vehicle, the means for predicting the imminent anomalous event may be independent from the vehicle, and the means for remediating the anomalous event may be independent from the vehicle.

With reference to the Figures, an apparatus **30** includes a robot body **32**, at least one sensor **34** coupled to the robot body **32** and positioned to receive stimuli from a passenger cabin **42** of a vehicle **40**, an actuatable component **36** coupled to the robot body **32**, and a computer **38** coupled to the robot body **32** and communicatively coupled to the sensor **34** and the actuatable component **36**. The computer **38** is programmed to predict an imminent anomalous event in the vehicle **40** based on data from the at least one sensor **34**, and in response to the determination, actuate the actuatable component **36** to address, e.g., remediate, the anomalous event.

The apparatus **30** can be actuated to help occupants of the vehicle **40** in response to an anomalous event. The apparatus **30** can act independently of the vehicle **40**. For example, the apparatus **30** has sensors **34** that can provide redundancy with sensors of the vehicle **40**. For another example, the apparatus **30** can act even if components of the vehicle **40** are disabled by the anomalous event. Furthermore, the apparatus **30** can perform actions that are useful after an anomalous event, such as extinguishing a fire or providing an exit from the vehicle **40**. The apparatus **30** may be particularly helpful for vulnerable occupants such as children or people with disabilities. The apparatus **30** can predict the anomalous event before the anomalous event occurs, permitting a faster response to the anomalous event.

With reference to FIG. **1**, the vehicle **40** may be any passenger or commercial automobile such as a car, a truck, a sport utility vehicle, a crossover, a van, a minivan, a taxi, a bus, etc.

The vehicle **40** includes the passenger cabin **42** to house occupants of the vehicle **40**. The passenger cabin **42** includes one or more front seats **44** disposed at a front of the passenger cabin **42** and one or more back seats **46** disposed behind the front seats **44**. The passenger cabin **42** may also

include third-row seats **48** at a rear of the passenger cabin **42**. In FIG. **1**, the front seats **44** and back seats **46** are shown to be bucket seats, and the third-row seats **48** are shown to be bench seats, but the seats **44**, **46**, **48** may be other types. The position and orientation of the seats **44**, **46**, **48** and components thereof may be adjustable by an occupant.

The apparatus **30** is positioned inside the passenger cabin **42**. The apparatus **30** can rest in a preset resting position. The resting position can be chosen to provide the sensors **34** of the apparatus **30** a field of view through windows of the vehicle **40** and to minimize obstruction of occupants of the vehicle **40**. For example, the apparatus **30** may rest on a floor of the passenger cabin **42**, as shown in FIG. **1**. For another example, the apparatus **30** may rest on one of the seats **44**, **46**, **48**.

The apparatus **30** is separate from and unattached to the vehicle **40**. The apparatus **30** can freely move around the passenger cabin **42** and can act independently of the vehicle **40**. All the components of the apparatus **30** are independent of the vehicle **40**. The apparatus **30** thus provides protections for occupants, described below, in addition to and redundant of what the vehicle **40** provides.

With reference to FIG. **2**, the apparatus **30** includes the robot body **32**. The robot body **32** can be a rigid frame and/or rigid shell to house and/or provide a mounting point for other components of the apparatus **30**. As shown in FIG. **2**, the robot body **32** can have a generally cylindrical shape, but other shapes are also possible.

The apparatus **30** includes a locomotion component **50** coupled to the robot body **32**. The locomotion component **50** is operable to move the apparatus **30** around the passenger cabin **42**. For example, the locomotion component **50** can include tracks, as shown in FIG. **2**. Alternatively or additionally, the locomotion component **50** can include wheels or legs. The locomotion component **50** can move around in the passenger cabin **42** by, e.g., traveling along a floor of the passenger cabin **42**. The floor of the passenger cabin **42** can be flat to accommodate movement by the apparatus **30**, and spaces can exist within each row of seats **44**, **46**, **48** except for the rearmost row, e.g., between the front seats **44** and between the back seats **46**, as shown in FIG. **1**. The apparatus **30** can be positioned so that the apparatus **30** is out of the way of the occupants unless needed.

The apparatus **30** can include a plurality of the sensors **34**. The sensors **34** are positioned to receive stimuli from the passenger cabin **42** of the vehicle **40**. The sensors **34** include a temperature sensor. The temperature sensor detects a temperature of a surrounding environment or an object in contact with the temperature sensor. The temperature sensor may be any device that generates an output correlated with temperature, e.g., a thermometer, a bimetallic strip, a thermistor, a thermocouple, a resistance thermometer, a silicon bandgap temperature sensor, etc. The sensors **34** include a smoke detector. The smoke detector can be any suitable type, e.g., ionization, photoelectric, aspirating, laser, etc. The sensors **34** can include detectors for other type(s) of toxic gas, such as fumes from a failure of batteries of the vehicle **40**. The sensors **34** can include pressure sensors to detect an air pressure of the passenger cabin **42**. The sensors **34** include one or more cameras. The cameras can detect electromagnetic radiation in some range of wavelengths. For example, the cameras may detect visible light, infrared radiation, ultraviolet light, or some range of wavelengths including visible, infrared, and/or ultraviolet light. The cameras are positioned on the robot body **32** so that when the apparatus **30** is in the resting position, the cameras have a field of view through the windows of the vehicle. The sensors **34** can include a microphone. The sensors **34** may include sensors for detecting the location and/or orientation of the apparatus **30**. For example, the sensors **34** may include global positioning system (GPS) sensors; accelerometers such as piezo-electric or microelectromechanical systems (MEMS); gyroscopes such as rate, ring laser, or fiber-optic gyroscopes; inertial measurements units (IMU); and magnetometers.

At least one actuatable component **36** is coupled to the robot body **32**. An actuatable component **36** can be actuated by the computer **38** to perform a task. Actuatable components **36** can include, for example and without limitation, a fire extinguisher **52**, a striker **54** and actuator **56**, automatic doors **58** concealing breathing masks **60**, and a gas supply **62** for supplying the breathing masks **60**.

The fire extinguisher **52** includes a pressure vessel storing expellant and firefighting agent and a nozzle through which the expellant and firefighting agent can be directed. The computer **38** can actuate the fire extinguisher **52** to allow the expellant to force the firefighting agent through the nozzle. The fire extinguisher **52** can use any suitable expellant, e.g., compressed nitrogen or carbon dioxide, and any suitable firefighting agent, e.g., dry chemicals such as monoammonium phosphate, sodium bicarbonate, etc.; foams; water; wet chemicals; etc.

The striker **54** and actuator **56** are actuatable to break out one of the windows of the vehicle **40**. The striker **54** and actuator **56** are mounted to the robot body **32**, e.g., as shown in FIG. **2**, on a top of the robot body **32**. The striker **54** is movable by the actuator **56**. The actuator **56** is equipped to move the striker **54** at a sufficiently high speed relative to the robot body **32** to break tempered glass. For example, the actuator **56** can be a compressed gas chamber releasable to launch the striker **54** out of a tube.

The illustrated apparatus **30** includes a plurality of the breathing masks **60**. The breathing masks **60** can be concealed by the automatic doors **58**, which are openable to reveal the breathing masks **60** if needed. For example, the automatic doors **58** can be opened by actuatable solenoids. The breathing masks **60** can be removed by occupants of the vehicle **40** to supply oxygen in the case of poor air quality inside the passenger cabin **42**. The breathing masks **60** are shaped to cover a mouth and nose of an occupant. The gas supply **62** can supply the breathing masks **60** with breathable air, e.g., compressed oxygen. The apparatus **30** can further include a defibrillator **70** that is concealed by the automatic doors **58**.

With reference to FIG. **3**, the computer **38** is a microprocessor-based computing device, e.g., an electronic controller or the like. The computer **38** includes a processor, a memory, etc. The memory of the computer **38** includes media for storing instructions executable by the processor as well as for electronically storing data and/or databases. The computer **38** is coupled to the robot body **32**, e.g., mounted inside the robot body **32**. The computer **38** is communicatively coupled to the sensors **34**, the locomotion component **50**, the actuatable components **36** (e.g., the fire extinguisher **52**, the actuator **56**, the automatic doors **58**, the gas supply **62**, etc.), and a transceiver **64**, e.g., via a bus.

The apparatus **30** includes a battery **66**. The battery **66** is electrically coupled to the computer **38**, the sensors **34**, the locomotion component **50**, the actuatable components **36**, and the transceiver **64**. The battery **66** is coupled to the robot body **32**. The battery **66** can be any suitable type for supplying power for the apparatus **30** to operate, e.g., lithium-ion batteries, nickel-metal hydride batteries, lead-

acid batteries, etc. The battery **66** permits the apparatus **30** to operate independently of a power supply from the vehicle **40**.

The transceiver **64** may be adapted to transmit signals wirelessly through any suitable wireless communication protocol, such as Bluetooth®, WiFi, IEEE 802.11a/b/g, other RF (radio frequency) communications, etc. The transceiver **64** may be adapted to communicate with a remote server **68**, that is, a server distinct and spaced from the apparatus **30**. The remote server **68** may be located outside the vehicle **40**. For example, the remote server **68** may be associated with a facility associated with the apparatus **30**, an infrastructure component (e.g., C-V2X, V2I communications via Dedicated Short-Range Communications (DSRC) or the like), an emergency responder, a mobile device associated with the owner or operator of the vehicle **40**, etc. The transceiver **64** may be one device or may include a separate transmitter and receiver.

FIG. **4** is a process flow diagram illustrating an exemplary process **400** for operating the apparatus **30** in response to an anomalous event. For the purposes of this disclosure, an "anomalous event" is defined as a sudden occurrence that raises the possibility of endangering the occupants of the vehicle **40**. The memory of the computer **38** stores executable instructions for performing the steps of the process **400**. As a general overview of the process **400**, the computer **38** receives data from the sensors **34**; transmits data to the remote server **68**; in response to predicting an impact, determining an anomalous event, or receiving a message from the remote server **68**, determines actions to remediate the anomalous event; and actuates one or more of the actuatable components **36** to perform the actions.

The process **400** begins in a block **405**, in which the computer **38** receives data from the sensors **34**. The data includes temperature data, data indicating the presence or absence of smoke, image data, audio data, location data, and kinematic data, i.e., data indicating the velocity and acceleration in linear and rotational dimensions.

Next, in a block **410**, the computer **38** instructs the transceiver **64** to transmit the data received from the cameras and/or microphone of the sensors **34** to the remote server **68**. The computer **38** can instruct the transceiver to transmit the data in real time, i.e., continuously transmitting the image data and audio data to the remote server **68** as the computer **38** receives the data. At the remote server **68**, the data may be automatically or manually monitored.

Next, in a process **500** as more fully described below, the computer **38** predicts an imminent anomalous event, such as an impact to the vehicle **40**, based on the data received from the sensors **34**. The output of the process **500** is an indication of whether an anomalous event will occur and a time to anomaly, i.e., an estimated time until the anomalous event occurs.

Next, in a decision block **415**, the computer **38** determines whether an anomalous event is predicted. In response to the prediction that an anomalous event will occur, the process **400** proceeds to a block **420**. If there is no prediction of the anomalous event, the process **400** proceeds to a block **425**.

In the block **420**, the computer **38** outputs a message to occupants in the passenger cabin **42**. The message can be visual, e.g., blinking lights, or auditory, e.g., a siren or a prerecorded or synthesized spoken message. After the block **420**, the process **400** proceeds to a block **440**.

In the block **425**, the computer **38** determines whether the vehicle **40** has experienced an anomalous event based on the data received from the sensors **34**. The computer **38** can determine whether the data indicates that a quantity has exceeded a threshold. For example, the computer **38** can determine from the temperature data whether a temperature of the passenger cabin **42** has exceeded a temperature threshold. The temperature threshold can be chosen to correspond to a fire occurring in the passenger cabin **42**. For another example, the computer **38** can determine whether data from the smoke detector indicates that a concentration of smoke in the passenger cabin **42** has exceeded a concentration threshold. The concentration threshold can be chosen to correspond to a fire occurring in the passenger cabin **42** or to correspond to a concentration of smoke known to be dangerous. For another example, the computer **38** can determine from other sensors **34** whether a toxic gas is present. For another example, the computer **38** can determine whether acceleration data has exceeded a first acceleration threshold. The acceleration that is compared to the first acceleration threshold can be a magnitude of an acceleration vector, i.e.,

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2},$$

in which a_i is acceleration along the ith axis, x is a vehicle-forward axis, y is a vehicle-lateral axis, and z is a vehicle-vertical axis. The first acceleration threshold can be chosen to correspond to the magnitude of acceleration that occurs during an impact based on, e.g., historical accident data.

Next, in a decision block **430**, the computer **38** determines whether the anomalous event occurred, e.g., whether one of the threshold values described with respect to the block **425** were exceeded. If so, the process **400** proceeds to the block **440**. If not, the process **400** proceeds to a decision block **435**.

In the decision block **435**, the computer **38** determines whether a message has been received from the remote server **68** via the transceiver **64** instructing the computer **38** to perform a responsive action to address an anomalous event. The remote server **68** may detect that an anomalous event has occurred that the apparatus **30** is not equipped to detect, and the remote server **68** will in that case transmit a message instructing the apparatus **30** to perform an action. If the computer **38** has received the message, the process **400** proceeds to the block **440**. If not, the process **400** returns to the block **405** to continue monitoring the data from the sensors **34**.

In the block **440**, the computer **38** determines which actions to perform to address the anomalous event. The block **440** occurs after the block **420** if an anomalous event was predicted, after the decision block **430** if an anomalous event was determined to have occurred, or after the decision block **435** if the computer **38** received a message from the remote server **68** instructing the computer **38** to perform an action. The computer **38** determines the action based on the data from the sensors **34** or based on the message from the remote server **68**. If the anomalous event is predicted rather than having already occurred, then the computer **38** can wait for the time to anomaly before acting.

If the data from the sensors **34** indicate that a fire is occurring in the passenger cabin **42**, the computer **38** determines to actuate the fire extinguisher **52**. For example, data indicating a fire can include temperature data indicating that the temperature of the passenger cabin **42** is above the temperature threshold. The temperature threshold can be the same temperature threshold as used in the block **425**. For another example, data indicating a fire can include data from the smoke detector indicating that the concentration of smoke in the passenger cabin **42** is above a first concentra-

tion threshold. The first concentration threshold can be chosen to correspond to a fire occurring in the passenger cabin **42**. For another example, the sensors **34** can include an infrared camera, and data from the infrared camera can indicate a hot spot above a temperature threshold.

If the data from the sensors **34** indicate the presence of smoke in the passenger cabin **42**, the computer **38** determines to provide the breathing masks **60** to the occupants and/or provide an exit for occupants from the passenger cabin **42**. For example, data indicating smoke can include data from the smoke detector indicating that the concentration of smoke in the passenger cabin **42** is above a second concentration threshold. The second concentration threshold can be chosen to correspond to a concentration of smoke known to be dangerous to an occupant. (The concentration threshold discussed with respect to the block **425** can be the smaller of the first concentration threshold and the second concentration threshold.) For another example, data indicating smoke can include image data from a camera of the sensors **34** indicating the presence of smoke. The image data can indicate smoke by, for example, exhibiting a haziness above a threshold. Alternatively, the computer **38** can identify the smoke using conventional image-recognition techniques, e.g., a convolutional neural network programmed to accept images as input and output a score for smoke. A convolutional neural network includes a series of layers, with each layer using the previous layer as input. Each layer contains a plurality of neurons that receive as input data generated by a subset of the neurons of the previous layers and generate output that is sent to neurons in the next layer. Types of layers include convolutional layers, which compute a dot product of a weight and a small region of input data; pool layers, which perform a downsampling operation along spatial dimensions; and fully connected layers, which generate based on the output of all neurons of the previous layer. The final layer of the convolutional neural network generates a score for each potential type of object, and the final output is "smoke" if smoke has the highest score.

If the data from the sensors **34** indicate that the vehicle **40** is immobilized, the computer **38** determines to provide an exit for occupants from the passenger cabin **42**. For example, the computer **38** can determine whether the acceleration data has exceeded a second acceleration threshold. The acceleration that is compared to the acceleration threshold can be a magnitude of an acceleration vector, i.e.,

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2},$$

in which a_i is acceleration along the ith axis, x is a vehicle-forward axis, y is a vehicle-lateral axis, and z is a vehicle-vertical axis. The second acceleration threshold can be chosen to correspond to the magnitude of acceleration that occurs during an impact that likely renders the vehicle **40** immobile, based on historical accident data. The second acceleration threshold can be greater than the first acceleration threshold from the block **425**.

Next, in the block **445**, the computer **38** actuates the actuatable components **36** to remediate the anomalous event by performing the actions selected in the block **440**. If the computer **38** has determined to actuate the fire extinguisher **52**, the computer **38** actuates the locomotion component **50** to move the apparatus **30** so that the apparatus **30** is close to the fire and the fire extinguisher **52** is aimed at the fire. To do so, the computer **38** can use data from the sensors **34** such as cameras to identify and locate the fire using object-recognition algorithms. The computer **38** then actuates the fire extinguisher **52** to release the expellant and firefighting agent.

If the computer **38** has determined to provide an exit for occupants from the passenger cabin **42**, the computer **38** actuates the locomotion component **50** to move the apparatus **30** so that the apparatus **30** is close to one of the windows and the striker **54** is aimed at the window. To do so, the computer **38** can use data from the sensors **34** such as cameras to identify and locate the window using object-recognition algorithms. The computer **38** then actuates the actuator **56** to launch the striker **54** at the window.

If the computer **38** has determined to provide the breathing masks **60** to the occupants, the computer **38** actuates the locomotion component **50** to move the apparatus **30** near one of the occupants. To do so, the computer **38** can use data from the sensors **34** such as cameras to identify and locate the occupants. The computer **38** can actuate the locomotion component **50** to move the apparatus **30** consecutively to each occupant. At the same time, the computer **38** actuates the automatic doors **58** to open and reveal the breathing masks **60** and the defibrillator **70**, and the computer **38** actuates the gas supply **62** to provide oxygen to the breathing masks **60**.

After the block **445**, the process **400** ends.

FIG. **5** is a process flow diagram illustrating an exemplary process **500** for predicting an impact to the vehicle **40**. The memory of the computer **38** stores executable instructions for performing the steps of the process **500**. As a general overview of the process **500**, the computer **38** performs sensor fusion in block **505**, determines a first time to anomaly based on vehicle kinematics in blocks **510-515**, determines a second time to anomaly based on pattern matching of sensor data in blocks **520-530**, and selects the lowest time to anomaly in block **535**. A "time to anomaly" is a length of time until a hazard occurs. The determinations of the first time to anomaly and the second time to anomaly are performed independently of each other, and the blocks **510-515** can be performed before, after, or in parallel with the blocks **520-530**.

The process **500** begins in a block **505**, in which the computer **38** performs sensor fusion of the data received from the sensors **34** in the block **405**. Sensor fusion is combining data from disparate sources together so that the resulting data has less uncertainty than if the data from each source were used individually. The sensor fusion can be low, medium, high, or multiple level. The sensor fusion can be performed with one or more algorithms, e.g., Kalman filter, central limit theorem, Bayesian networks, Dempster-Shafer, convolutional neural networks, etc.

Next, in a block **510**, the computer **38** generates a physics model describing a state of the vehicle **40**. The current state of the vehicle **40** can be described in with a set of kinematic variables, e.g., (x_x, x_y, x_z, v_x, v_y, v_z, a_x, a_y, a_z, θ_x, θ_y, θ_z, ω_x, ω_y, ω_z, α_x, α_y, α_z), in which x_i is position along the ith axis, v_i is velocity along the ith axis, a_i is acceleration along the ith axis, θ_i is angular position about the ith axis, ω_i is angular velocity about the ith axis, and α_i is angular acceleration about the ith axis, x is a vehicle-forward axis, y is a vehicle-left axis, and z is a vehicle-vertical axis. The kinematic variables can be determined from the acceleration data, e.g., by dead reckoning, as well as by location data such as GPS data.

Next, in a block **515**, the computer **38** determines whether conditions indicate a likely impact and, if so, estimates a first time to anomaly. The conditions are combinations of values for subsets of the kinematic variables indicating that an

impact is likely. For example, a value of angular acceleration α_x above a threshold can indicate that the vehicle **40** may tip over sideways, a value of lateral velocity a_y above a threshold can indicate that the vehicle **40** is skidding sideways, etc. For each condition, a corresponding first time to anomaly can be stored in the memory of the computer **38**, e.g., in a lookup table. The various first times to anomaly can be chosen based on physics modeling, historical accident data, etc. If none of the conditions are met, then the first time to anomaly is set to infinity or to an arbitrary value several times greater than the greatest first time to anomaly in the lookup table.

Next, in a block **520**, the computer **38** performs feature extraction on the fused sensor data. Feature extraction is picking out the potentially important features and eliminating less useful and redundant data. A feature is an individual measurable property or characteristic of a phenomenon being observed. Features can be determined using general dimensionality reduction techniques such as independent component analysis, latent semantic analysis, principal component analysis, multifactor dimensionality reduction, nonlinear dimensionality reduction, multilinear subspace learning, etc. Alternatively or additionally, features can be chosen by designers based on knowledge that the feature can indicate an impending impact to the vehicle **40**.

Next, in a block **525**, the computer **38** performs pattern matching on the features to determine whether an impact will likely occur. The pattern matching/recognition is based on a model created by a machine learning process, e.g., regression, classification, clustering, principal component analysis, ensemble learning, Bayesian networks, Markov random fields, sequence labeling, etc. The machine-learning model can be trained on naturalistic driving studies and accident databases maintained by, e.g., the Strategic Highway Research Program 2 (SHRP2), the German In-Depth Accident Study (GIDAS), the China In-Depth Accident Study (CIDAS), the National Highway Traffic Safety Administration (NHTSA), etc. The model includes a set of patterns, and the output of the pattern matching is which pattern the fused sensor data most closely resembles.

Next, in a block **530**, the computer **38** estimates a second time to anomaly based on which pattern was outputted in the block **525**. A lookup table can store second times to anomaly corresponding to the patterns. The second times to anomaly can be chosen based on the naturalistic driving studies and accident databases maintained by, e.g., SHRP2, GIDAS, CIDAS, NHTSA, etc. For patterns representing situations in which impacts did not occur, the second time to anomaly can be set to infinity or to an arbitrary value several times greater than the greatest second time to anomaly in the lookup table.

Next, in a block **535**, the computer **38** selects the shorter of the first time to anomaly and the second time to anomaly as the time to anomaly. The time to anomaly can represent whether an impact is predicted based on the magnitude of the time to anomaly. If the time to anomaly is as great as the arbitrary large values chosen to non-impact situations in the blocks **515** and **530**, then an impact is not predicted; if the time to anomaly is shorter, then an impact is predicted. After the block **535**, the process **500** ends.

In general, the computing systems and/or devices described may employ any of a number of computer operating systems, including, but by no means limited to, versions and/or varieties of the Ford Sync® application, AppLink/Smart Device Link middleware, the Microsoft Automotive® operating system, the Microsoft Windows® operating system, the Unix operating system (e.g., the Solaris® operating system distributed by Oracle Corporation of Redwood Shores, Calif.), the AIX UNIX operating system distributed by International Business Machines of Armonk, N.Y., the Linux operating system, the Mac OSX and iOS operating systems distributed by Apple Inc. of Cupertino, Calif., the BlackBerry OS distributed by Blackberry, Ltd. of Waterloo, Canada, and the Android operating system developed by Google, Inc. and the Open Handset Alliance, or the QNX® CAR Platform for Infotainment offered by QNX Software Systems. Examples of computing devices include, without limitation, an on-board vehicle computer, a computer workstation, a server, a desktop, notebook, laptop, or handheld computer, or some other computing system and/or device.

Computing devices generally include computer-executable instructions, where the instructions may be executable by one or more computing devices such as those listed above. Computer executable instructions may be compiled or interpreted from computer programs created using a variety of programming languages and/or technologies, including, without limitation, and either alone or in combination, Java™, C, C++, Matlab, Simulink, Stateflow, Visual Basic, Java Script, Python, Perl, HTML, etc. Some of these applications may be compiled and executed on a virtual machine, such as the Java Virtual Machine, the Dalvik virtual machine, or the like. In general, a processor (e.g., a microprocessor) receives instructions, e.g., from a memory, a computer readable medium, etc., and executes these instructions, thereby performing one or more processes, including one or more of the processes described herein. Such instructions and other data may be stored and transmitted using a variety of computer readable media. A file in a computing device is generally a collection of data stored on a computer readable medium, such as a storage medium, a random access memory, etc.

A computer-readable medium (also referred to as a processor-readable medium) includes any non-transitory (e.g., tangible) medium that participates in providing data (e.g., instructions) that may be read by a computer (e.g., by a processor of a computer). Such a medium may take many forms, including, but not limited to, non-volatile media and volatile media. Non-volatile media may include, for example, optical or magnetic disks and other persistent memory. Volatile media may include, for example, dynamic random access memory (DRAM), which typically constitutes a main memory. Such instructions may be transmitted by one or more transmission media, including coaxial cables, copper wire and fiber optics, including the wires that comprise a system bus coupled to a processor of a ECU. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, an EPROM, a FLASH-EEPROM, any other memory chip or cartridge, or any other medium from which a computer can read.

Databases, data repositories or other data stores described herein may include various kinds of mechanisms for storing, accessing, and retrieving various kinds of data, including a hierarchical database, a set of files in a file system, an application database in a proprietary format, a relational database management system (RDBMS), a nonrelational database (NoSQL), a graph database (GDB), etc. Each such data store is generally included within a computing device employing a computer operating system such as one of those mentioned above, and are accessed via a network in any one or more of a variety of manners. A file system may be

accessible from a computer operating system, and may include files stored in various formats. An RDBMS generally employs the Structured Query Language (SQL) in addition to a language for creating, storing, editing, and executing stored procedures, such as the PL/SQL language mentioned above.

In some examples, system elements may be implemented as computer-readable instructions (e.g., software) on one or more computing devices (e.g., servers, personal computers, etc.), stored on computer readable media associated therewith (e.g., disks, memories, etc.). A computer program product may comprise such instructions stored on computer readable media for carrying out the functions described herein.

In the drawings, the same reference numbers indicate the same elements. Further, some or all of these elements could be changed. With regard to the media, processes, systems, methods, heuristics, etc. described herein, it should be understood that, although the steps of such processes, etc. have been described as occurring according to a certain ordered sequence, such processes could be practiced with the described steps performed in an order other than the order described herein. It further should be understood that certain steps could be performed simultaneously, that other steps could be added, or that certain steps described herein could be omitted.

All terms used in the claims are intended to be given their plain and ordinary meanings as understood by those skilled in the art unless an explicit indication to the contrary in made herein. In particular, use of the singular articles such as "a," "the," "said," etc. should be read to recite one or more of the indicated elements unless a claim recites an explicit limitation to the contrary.

The disclosure has been described in an illustrative manner, and it is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present disclosure are possible in light of the above teachings, and the disclosure may be practiced otherwise than as specifically described.

What is claimed is:

1. An apparatus comprising:
- a robot body;
- at least one sensor coupled to the robot body and positioned to receive stimuli from a passenger cabin of a vehicle;
- an actuatable component coupled to the robot body; and
- a computer coupled to the robot body and communicatively coupled to the sensor and the actuatable component;
- wherein the computer is programmed to:
  - receive data from the at least one sensor gathered while the robot body and the at least one sensor are positioned inside the passenger cabin of the vehicle;
  - predict an imminent anomalous event in the vehicle based on the data from the at least one sensor; and
  - in response to the prediction, actuate the actuatable component to remediate the anomalous event.

2. The apparatus of claim **1**, wherein remediating the anomalous event includes providing an exit for occupants from the passenger cabin.

3. The apparatus of claim **1**, wherein remediating the anomalous event includes extinguishing a fire.

4. The apparatus of claim **1**, wherein the apparatus is unattached to the vehicle.

5. The apparatus of claim **1**, further comprising a locomotion component coupled to the robot body.

6. The apparatus of claim **5**, wherein the locomotion component includes at least one of wheels, tracks, or legs.

7. The apparatus of claim **1**, wherein the actuatable component includes a fire extinguisher.

8. The apparatus of claim **1**, wherein the actuatable component includes an actuator and a striker movable by the actuator relative to the robot body, wherein the actuator is equipped to move the striker at a sufficiently high speed relative to the robot body to break tempered glass.

9. The apparatus of claim **1**, further comprising a plurality of breathing masks detachably attached to the robot body.

10. The apparatus of claim **1**, wherein the at least one sensor includes a temperature sensor.

11. The apparatus of claim **1**, wherein the at least one sensor includes a smoke detector.

12. The apparatus of claim **1**, further comprising a transceiver coupled to the robot body and communicatively coupled to the computer, wherein the at least one sensor includes a camera, and the computer is further programmed to instruct the transceiver to transmit data received from the camera to a remote server.

13. The apparatus of claim **12**, wherein the computer is further programmed to instruct the transceiver to transmit the data received from the camera to the remote server in real time.

14. The apparatus of claim **12**, wherein the computer is further programmed to, in response to a message from the remote server, actuate the actuatable component to provide an exit for occupants from the passenger cabin or to extinguish a fire.

15. The apparatus of claim **1**, further comprising a battery coupled to the robot body and electrically coupled to the computer, the at least one sensor, and the actuatable component.

16. A computer comprising a processor and a memory storing instructions executable by the processor to:
- receive data from at least one sensor mounted to an apparatus gathered while the apparatus and the at least one sensor are positioned inside a passenger cabin of a vehicle, wherein the apparatus is unattached to the vehicle;
- predict an imminent anomalous event in the vehicle based on the data received from the at least one sensor; and
- in response to the prediction, actuate an actuatable component of the apparatus to remediate the anomalous event.

17. An apparatus comprising:
- a robot body;
- means for moving the robot body around inside a passenger cabin of a vehicle;
- at least one sensor mounted to the robot body;
- means, mounted to the robot body, for remediating the anomalous event; and
- a computer programmed to:
  - receive data from the at least one sensor gathered while the robot body and the at least one sensor are positioned inside the passenger cabin of the vehicle;
  - predict an imminent anomalous event in the vehicle based on the data from the at least one sensor; and
  - upon predicting the imminent anomalous event, activate the means for remediating the anomalous event.

18. The apparatus of claim **17**, further comprising means for protecting occupants of the passenger cabin from smoke.

19. The apparatus of claim **17**, wherein the means for moving the robot body around is independent of the vehicle, the means for predicting the imminent anomalous event is

independent from the vehicle, and the means for remediating the anomalous event is independent from the vehicle.

20. The apparatus of claim **1**, wherein the imminent anomalous event is a future event when predicted.

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