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(54) **SYSTEMS AND METHODS FOR ACTIVE MITIGATION OF SUDDEN ACCELERATIVE FORCES IN VEHICLES**

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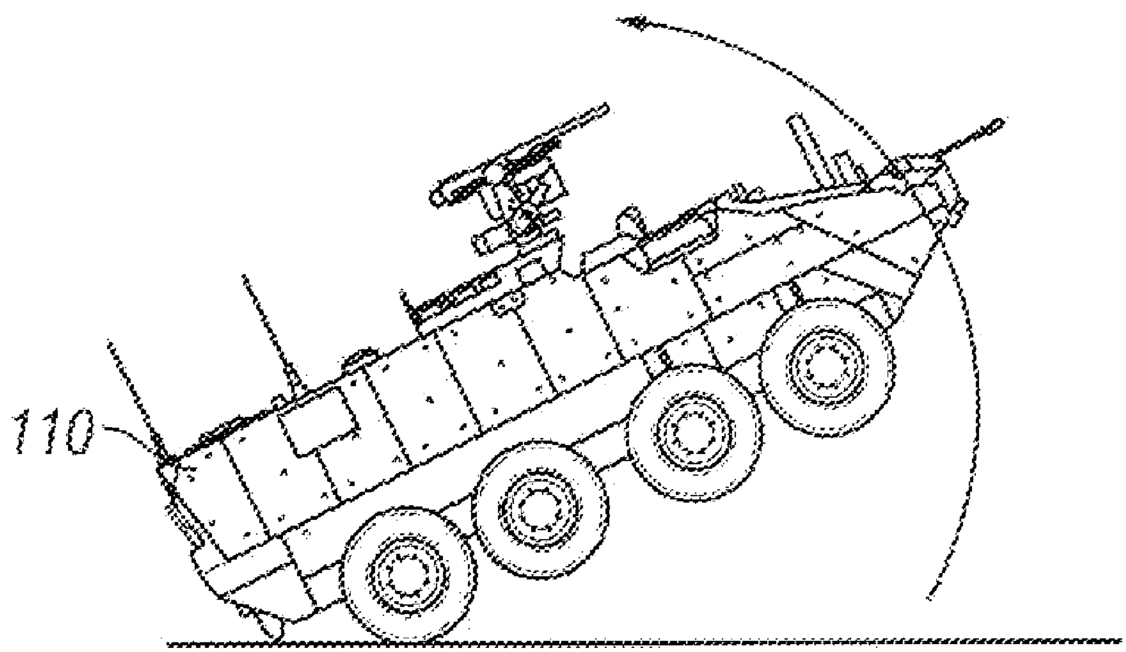
(52) **U.S. Cl.** **701/36**; 701/1

(57) **ABSTRACT**

An active blast mitigation system includes one or more sensors configured to produce a set of acceleration signals indicative of a dynamic response of the vehicle. A control system communicatively coupled to the plurality of sensors is configured to determine the dynamic response of the vehicle based on the set of acceleration signals and determine whether mitigation is required based on the dynamic response of the vehicle. If it is determined that mitigation is required, the control system produces one or more countermeasure signals selected to at least partially counteract the dynamic response. Countermeasure assemblies communicatively coupled to the control system are configured to activate in response to the one or more countermeasure signals.



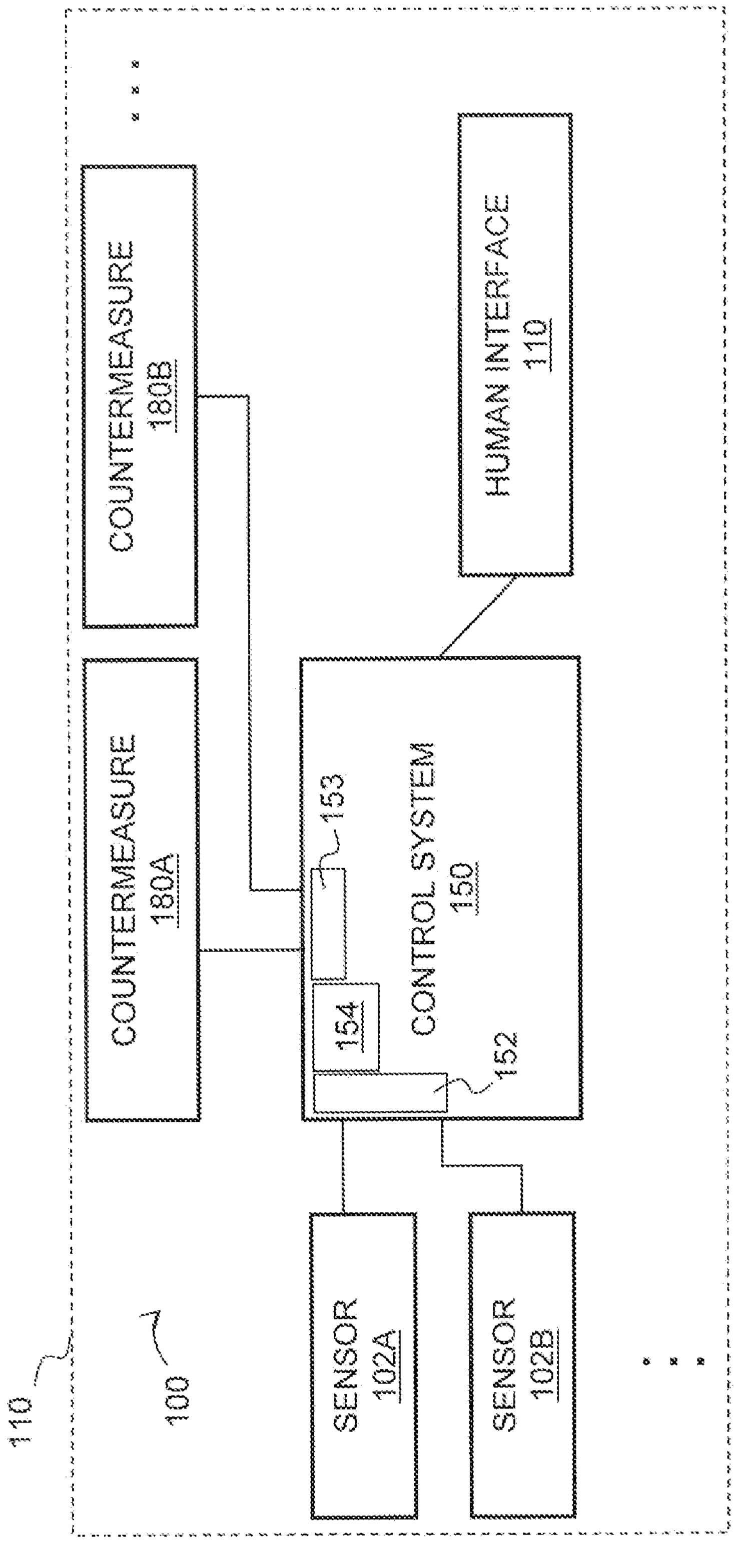

COUNTERMEASURE
180B
HUMAN INTERFACE
110
COUNTERMEASURE
180A
CONTROL SYSTEM
150
153
154
152
SENSOR
102A
SENSOR
102B
110
100

FIG. 1

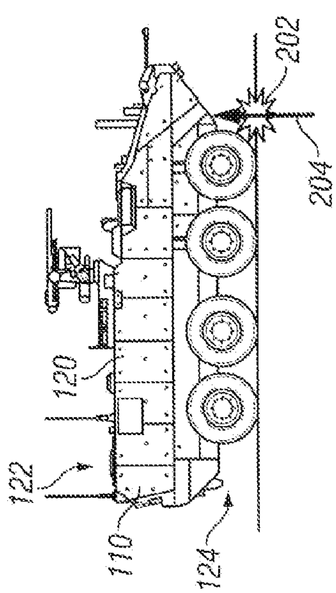


FIG. 2A

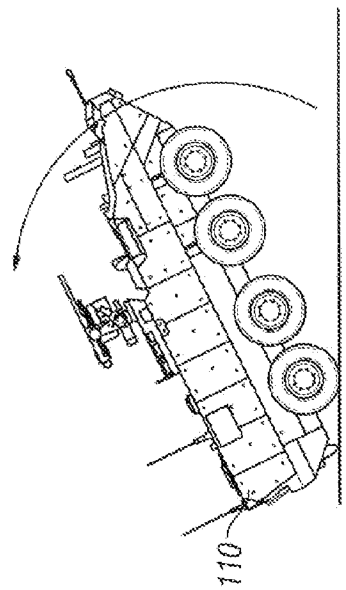


FIG. 2B

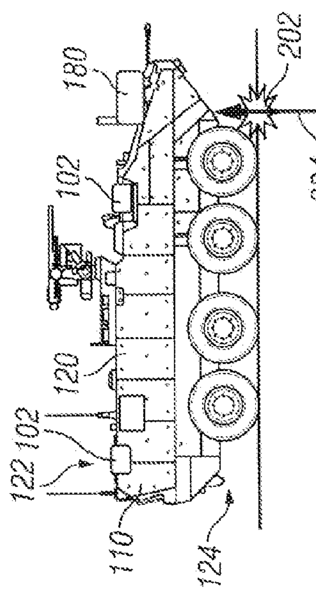


FIG. 3A

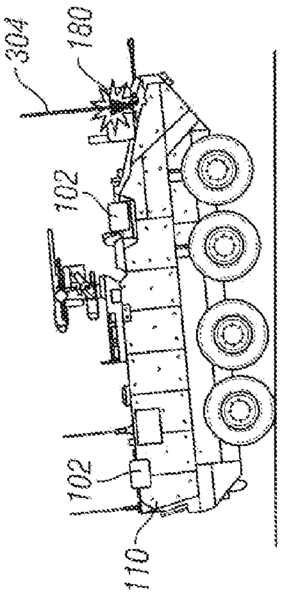


FIG. 3B

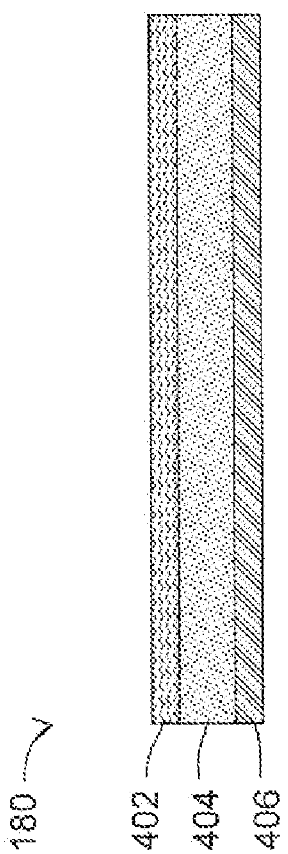


FIG. 4

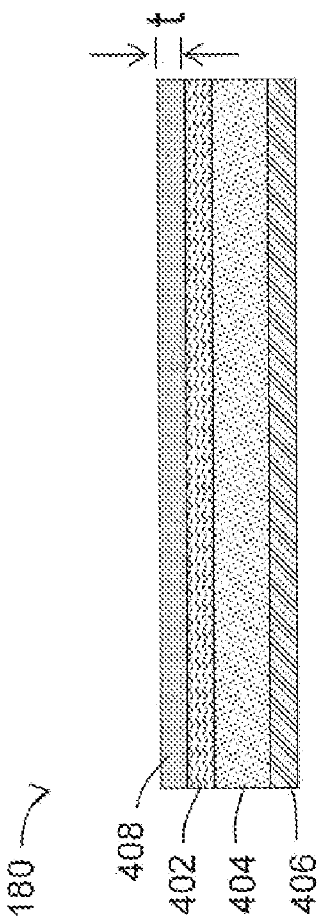


FIG. 5

SYSTEMS AND METHODS FOR ACTIVE MITIGATION OF SUDDEN ACCELERATIVE FORCES IN VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Prov. Pat. No. 61/453,421, filed Mar. 16, 2011, which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] This invention generally relates to vehicular safety systems, and more particularly relates to systems and methods for mitigating the effects of sudden accelerative forces on vehicles due to, for example, land mines and improvised explosive devices (IEDs).

BACKGROUND OF THE INVENTION

[0003] Vehicles, particularly military vehicles, often experience sudden accelerative forces due to land mine blasts, improvised explosive devices (IEDs), and other types of explosive events. In many cases, the basic hull structure of the vehicle is sufficiently robust and structurally sound to withstand such blasts. However, even when the hull itself is intact, the sudden rotation and/or translation of the vehicle can cause excessive and possibly fatal accelerative forces on the occupants of the vehicle.

[0004] For example, in the event that a land mine explodes near the front end of a vehicle, the upward blast force experienced by the underbelly of the vehicle will often cause sudden upward rotation of the vehicle's front end accompanied by a general upward translation of the vehicle. While various restraint systems such as break-away seating have been proposed to address this problem, such sudden accelerations can still pose a major survivability risk to the occupants of the vehicle, even if those occupants are well-restrained.

[0005] Accordingly, there is a need for improved vehicular safety systems, particularly systems and methods for mitigating the effects of sudden accelerative forces produced by mines and the like.

BRIEF SUMMARY OF THE INVENTION

[0006] In accordance with one embodiment, a method of mitigating sudden accelerative forces experienced by a vehicle includes determining a dynamic response of the vehicle resulting from the sudden accelerative forces, determining whether mitigation is required based on the dynamic response of the vehicle, and, if it is determined that mitigation is required, activating one or more countermeasures to generate mitigating forces on the vehicle such that the sudden accelerative forces are at least partially counteracted.

[0007] An active blast mitigation system in accordance with one embodiment includes: one or more sensors configured to produce a set of acceleration signals indicative of a dynamic response of the vehicle; a control system communicatively coupled to the plurality of sensors, the control system configured to determine the dynamic response of the vehicle based on the set of acceleration signals, determine whether mitigation is required based on the dynamic response of the vehicle, and, if it is determined that mitigation is required, produce one or more countermeasure signals, the countermeasure signals selected to at least partially counteract the dynamic response; and a plurality of countermeasure assemblies communicatively coupled to the control system, the plurality of countermeasure assemblies configured to activate in response to the one or more countermeasure signals.

[0008] An active mine blast mitigation control system in accordance with one embodiment includes: an input interface configured to be coupled to one or more acceleration sensors and to receive a set of acceleration signals indicative of a dynamic response of a vehicle; an output interface configured to be coupled to one or more countermeasure assemblies and to transmit one or more countermeasure signals thereto; and a processor communicatively coupled to the input interface and the output interface, the processor configured to determine the dynamic response of the vehicle based on the set of acceleration signals, determine whether mitigation is required based on the dynamic response of the vehicle, and, if it is determined that mitigation is required, produce the one or more countermeasure signals.

BRIEF DESCRIPTION OF DRAWINGS

[0009] The preferred exemplary embodiment of the present invention will hereinafter be described in conjunction with the appended drawings, where like designations denote like elements, and:

[0010] FIG. **1** is a block diagram of an exemplary active mitigation system in accordance with an embodiment of the invention;

[0011] FIGS. **2**A and **2**B conceptually depict sudden accelerative forces and resulting vehicular dynamic response caused by a blast event;

[0012] FIGS. **3**A and **3**B conceptually depict sudden accelerative forces and vehicular dynamic response caused by a blast event in accordance with an exemplary active mitigation system;

[0013] FIG. **4** is a conceptual cross-sectional view of an active countermeasure assembly in accordance with one embodiment of the invention; and

[0014] FIG. **5** is a conceptual cross-sectional view of an active countermeasure assembly in accordance with an alternate embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

[0016] Referring now to FIG. **1**, an active blast mitigation system **100** in accordance with one embodiment of the present invention generally includes one or more sensors **102** (**102**A, **102**B, etc.), a control system **150**, a plurality of countermeasure assemblies (or simply "countermeasures") **180** (**180**A, **180**B, etc.), and a human interface **110**.

[0017] In general, sensors **102** are configured to produce a set of acceleration signals indicative of a dynamic response of a vehicle **110**. Note that, for the purposes of simplicity, vehicle **110** is illustrated conceptually as a rectangle. Control system **150**, which is communicatively coupled to the plurality of sensors **102** and countermeasures **180**, is configured to determine the dynamic response of vehicle **110** based on the set of acceleration signals, then determine whether mitigation is required based on the dynamic response of the vehicle—e.

g., whether the dynamic response of the vehicle likely to cause harm to occupants of the vehicle. If it is determined that mitigation is required, control system **150** produces one or more countermeasure signals selected to at least partially counteract the dynamic response (e.g., to counteract the effects of sudden accelerative forces applied to vehicle **110** by a mine blast). Countermeasures **180** then activate in response to the one or more countermeasure signals, thereby at least partially counteracting the dynamic response of vehicle **110**.

[0018] Sensors **102** include any combination of sensor components, processors, and/or software configured to produce a set of acceleration signals indicative of a dynamic response of a vehicle **110**. Sensors **102** may be communicatively coupled to control system **150** in any suitable fashion, including various wired or wireless communication methods known in the art. In one embodiment, sensors **102** are selected such that they can detect a blast event in approximately 10 milliseconds or less. An example sensor suitable for use with the present invention is the Measurement Specialties model MEAS 53-200 piezoresistive accelerometer, having an acceleration limit of 2000 g's and a frequency limit of about 5 kHz (200 microseconds per reading). Sensors **102** may be placed anywhere on, under, or within vehicle **110**. In one embodiment, for example, sensors **102** are placed near at least three corners of vehicle **110** as well as near the center of the vehicle. In this way, both the translation and rotation of vehicle **110** with respect to various axes may be inferred via acceleration information received from sensors **102**.

[0019] Control system **150** includes, in one embodiment, a processor **154** (e.g., one or more microprocessors, microcontrollers, or the like), an input interface **152**, and an output interface **153**. As will be apparent, in practical embodiments control system **150** will generally include any number of additional components, such as power supplies, memory and storage components, and the like. For the purposes of simplicity, such components are not illustrated in FIG. **1**.

[0020] Input interface **152** is configured to be coupled to sensors **102**, and to receive a set of acceleration signals indicative of the dynamic response of vehicle **110**. Such signals may be digital or analog. Similarly, output interface **153** is configured to be coupled to countermeasures **180** and to transmit one or more countermeasure signals thereto. The countermeasure signals may also be either digital or analog. Processor **154** is communicatively coupled to input interface **152** and to output interface **153**. Processor **154** is configured to determine the dynamic response of vehicle **110** based on the set of acceleration signals. Processor **154** is further configured to determine whether mitigation is required based on the dynamic response of the vehicle. If processor **154** determines that mitigation is required, it produces one or more countermeasure signals in order to activate the appropriate countermeasures **180**.

[0021] Control system **150** may determine the dynamic response of vehicle **110** from acceleration signal in accordance with classical Newtonian physics, which are well known in the art. That is, since control system **150** will know a priori the location of sensors **102** with respect to the approximate center of mass of vehicle **110**, as well as the vector acceleration at each of those points, control system **150** can resolve the vector quantities to determine the position, velocity, acceleration, instant center, and other common dynamic characteristics of the structure.

[0022] FIGS. **2**A and **2**B depict an exemplary vehicle **110** subject to a sudden accelerative force **204** produced by a blast (e.g., a mine blast) **202** without an active mitigation system as illustrated in FIG. **1**. In this embodiment, vehicle **110** includes a hull **120**, such that force **204** is primarily experienced by the underbelly **124** of hull **120** (FIG. **2**A). For the purpose of this illustration, it is assumed that the right end of vehicle **110** corresponds to the "front end", and that the left end of vehicle **110** corresponds to the "back end." As a result of force **204**, which is distant from the center of mass of vehicle **110** (not illustrated), the front end rises quickly such that vehicle **110** experiences a sudden rotation—i.e., a counter-clockwise rotation as illustrated in FIG. **2**B. In general, the accelerative loading generated by the blast at a given location in vehicle **110** can be characterized by the value ΔV, which is the velocity change occurring at that location due to blast **202**. For an off-center blast, a point closer to an end of the vehicle will have a larger value of ΔV than one closer to the center of mass, simply due to the effect of rotational dynamics. In some blast instances, the front end may rise at about 6.0 m/s and reach about two meters off the ground. As mentioned previously, such sudden acceleration can pose a severe risk to any occupants of vehicle **110**.

[0023] FIGS. **3**A and **3**B, in contrast, depict an exemplary vehicle **110** subject to sudden accelerative force **204** produced by blast **202** with an active mitigation system as illustrated in FIG. **1**. In FIG. **3**A, two sensors **102** are illustrated as being mechanically coupled to hull **120** near one end of vehicle **110**. It will be appreciated, however, that any number of such sensors **102** may be distributed on, under, or within vehicle **110**. Similarly, while a single countermeasure **180** is illustrated as being coupled to hull **120** near the front end of vehicle **110**, any number of such countermeasures may be employed.

[0024] As depicted in FIG. **3**B, when the control system (not illustrated) determines that mitigation is required based on the dynamic response of the vehicle (e.g., based on the translation and rotation sensed via sensors **102**), the control system produces and sends to countermeasure **180** a countermeasure signal to at least partially counteract the effects of sudden accelerative forces applied to vehicle **110** by mine blast **202**. Countermeasure **180** then activates (e.g., via controlled explosion) in response to the countermeasure signal, producing a mitigating force **304** that at least partially counteracts force **204**, thereby reducing the amplitude of rotation and/or translation experienced by vehicle **110**. This is shown qualitatively by the relative rotation of vehicle **110** in FIGS. **2**B and **3**B.

[0025] Countermeasures **180** include any combination of hardware and/or software suitable to receive a signal from control system **150** and then activate in response to that signal. As with sensors **102**, countermeasures **180** may be communicatively coupled to control system using any suitable wired or wireless communication method.

[0026] Referring to FIG. **4**, an exemplary countermeasure **180** suitable for use in implementations of the present invention generally includes an armor layer **404** (e.g., a ceramic layer), a hull **406** (corresponding, for example, to hull **120** in FIGS. **3**A and **3**B), and an energetic material layer **402**. Energetic material layer **402** generally comprises a material capable of reacting in a way that it imparts a force on the underlying structure (e.g., an explosive or propellant). In an alternate embodiment, as shown in FIG. **5**, counter measure **180** further includes a tamping layer **408** (e.g., a steel, aluminum, or other frangible material layer), as may be seen in reactive armor structures. Tamping layer **408** serves two purposes: it protects energetic material layer **402** from environmental damage, and it increases the net reaction force of a given amount of energetic material. That is, the same amount of energetic material layer **402** will generate more reaction force when "tamped" than when "untamped", and will reduce the total amount of energetic material needed to produce a given reaction load.

[0027] Energetic material layer **402** comprises, in various embodiments, either an explosive or a propellant. As is known in the art, an explosive reacts very quickly (often in less than a millisecond), and generates a focused (and possibly damaging) load over a small area in a very short time. In contrast, a propellant can be selected such that it reacts more slowly—for example, about 10-50 milliseconds or more—and thereby reduces the possibility of overstressing the underlying hull structure. In one embodiment, for example, energetic material layer **402** has a specific impulse of approximately 244 seconds (2395 N-s/kg), consistent with high-grade propellants. The thickness of energetic material layer **402** may also be selected in accordance with the desired effect. In one embodiment, energetic material layer **402** has a thickness of about 0.25 inches.

[0028] Materials suitable for implementing energetic material layer **402** include, for example, the Detasheet flexible rubberized energetic material manufactured by DuPont. Other non-explosive energetics such as a common aluminum-ammonium perchlorate propellant may also be used. In general, any energetic material layer **402** that is capable of producing a reaction force tailored to counteract the acceleration induced by the initial blast may be used. In one embodiment, the size, geometry, and material of countermeasures **180** are selected such that the structure can counter a 40 kN-s impulse, which roughly corresponds to a large underbelly mine blast.

[0029] Human interface **110** includes any combination of processors, memory, storage, displays, input devices (mice, keyboards, touch-screens, etc.) suitable for controlling operation of system **100**. That is, the control system **150** is configured to determine the dynamic response, determine whether mitigation is required, and produce the countermeasure signals in accordance with commands received from the human interface. In one embodiment, human interface **110** also includes various indicators providing information regarding the status of sensors **102** and countermeasures **180**. For example, human interface **110** might indicate whether and to what extent sensors **102** and countermeasures **180** are functional, and whether the system as a whole is armed or unarmed.

[0030] Thus, the embodiments and examples set forth herein were presented in order to best explain the present invention and its particular application and to thereby enable those skilled in the art to make and use the invention. However, those skilled in the art will recognize that the foregoing description and examples have been presented for the purposes of illustration and example only. The description as set forth is not intended to be exhaustive or to limit the invention to the precise form disclosed.

1. A method of mitigating sudden accelerative forces experienced by a vehicle, comprising:

determining a dynamic response of the vehicle resulting from the sudden accelerative forces;

determining whether mitigation is required based on the dynamic response of the vehicle; and

if it is determined that mitigation is required, activating one or more countermeasures to generate mitigating forces on the vehicle such that the sudden accelerative forces are at least partially counteracted.

2. The method of claim **1**, wherein determining the dynamic response comprises receiving a set of signals from one or more acceleration sensors mechanically coupled to the vehicle.

3. The method of claim **2**, wherein the one or more acceleration sensors include a first acceleration sensor proximate a first end of the vehicle, and a second acceleration sensor proximate a second end of the vehicle.

4. The method of claim **1**, wherein determining whether mitigation is required comprises determining whether the dynamic response of the vehicle has an amplitude that is greater than a predetermined threshold.

5. The method of claim **1**, wherein determining whether mitigation is required comprises determining whether the dynamic response of the vehicle is likely to cause damage to an occupant within the vehicle.

6. The method of claim **1**, further including determining the dynamic response, determining whether mitigation is required, and activating the one or more countermeasures is performed in accordance with commands received from a human interface.

7. The method of claim **1**, wherein the dynamic response of the vehicle is characterized by a rotation and a translation of the vehicle, and wherein activating the one or more countermeasures includes activating one or more countermeasures coupled to a topside of the vehicle such that the mitigating forces at least partially counteract the rotation and the translation of the vehicle.

8. An active blast mitigation system for a vehicle, comprising:

one or more sensors configured to produce a set of acceleration signals indicative of a dynamic response of the vehicle;

a control system communicatively coupled to the plurality of sensors, the control system configured to determine the dynamic response of the vehicle based on the set of acceleration signals, determine whether mitigation is required based on the dynamic response of the vehicle, and, if it is determined that mitigation is required, produce one or more countermeasure signals, the countermeasure signals selected to at least partially counteract the dynamic response; and

a plurality of countermeasure assemblies communicatively coupled to the control system, the plurality of countermeasure assemblies configured to activate in response to the one or more countermeasure signals.

9. The system of claim **8**, wherein the one or more sensors include a first acceleration sensor proximate a first end of the vehicle, and a second acceleration sensor proximate a second end of the vehicle.

10. The system of claim **8**, wherein the control system is configured to determine whether mitigation is required by determining whether an amplitude of the dynamic response is above a predetermined threshold.

11. The system of claim **8**, further including a human interface communicatively coupled to the control system, wherein the control system is configured to determine the dynamic response, determine whether mitigation is required, and produce the countermeasure signals in accordance with commands received from the human interface.

12. The system of claim **11**, wherein the human interface further includes status indicators indicating which of the countermeasure assemblies and sensors are functional, and whether the active blast mitigation system is armed.

13. The system of claim **8**, wherein the vehicle includes a hull, and wherein the plurality of countermeasure assemblies include at least one topside countermeasure assembly coupled to the top of the hull.

14. The system of claim **13**, wherein the at least one topside countermeasure includes:

an armor layer coupled to an external surface of the hull; and

an energetic material layer coupled to the armor layer.

15. The system of claim **14**, further including a tamping layer coupled to the energetic material layer.

16. The system of claim **15**, wherein the armor layer comprises a ceramic, the tamping layer comprises steel, and the thickness of the tamping layer is selected to provide a predetermined mitigating force when activated.

17. An active mine blast mitigation control system, comprising:

an input interface configured to be coupled to one or more acceleration sensors and to receive a set of acceleration signals indicative of a dynamic response of a vehicle;

an output interface configured to be coupled to one or more countermeasure assemblies and to transmit one or more countermeasure signals thereto;

a processor communicatively coupled to the input interface and the output interface, the processor configured to determine the dynamic response of the vehicle based on the set of acceleration signals, determine whether mitigation is required based on the dynamic response of the vehicle, and, if it is determined that mitigation is required, produce the one or more countermeasure signals.

18. The control system of claim **16**, wherein the processor is configured to determine whether mitigation is required by determining whether an amplitude of the dynamic response is above a predetermined threshold.

19. The control system of claim **16**, wherein the processor is communicatively coupled to a human interface, and wherein the processor is configured to determine the dynamic response, determine whether mitigation is required, and produce the countermeasure signals in accordance with commands received from the human interface.

20. The control system of claim **16**, wherein the control system is further configured to:

determine the dynamic response, determine whether mitigation is required, and produce the countermeasure signals in accordance with commands received from a human interface;

receive status information from the one or more countermeasure assemblies and the one or more sensors; and

transmit the status information to the human interface.

* * * * *