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(54) Method, apparatus, and system of providing sensor-based tactile feedback

(57) A method, system, and apparatus for providing feedback about firing on blueforce personnel (110,120) are provided. A blueforce soldier is armed with a weapon (112,122) that has one or more weapon sensors (350,360,370). The weapon sensors (350,360,370) may provide information about a direction of fire and a firing state of the weapon (112,122). A blueforce-injury-possibility calculator (240) may determine the direction of fire, the firing state, and an injury zone of the weapon (112,122) based on the information from the weapon sensors (350,360,370). The blueforce-injury-possibility calculator (240) may receive location information about one or more blueforce personnel (110,120). The blueforce-injury-possibility calculator (240) may then determine a blueforce-injury possibility based on the injury zone and the location information. Tactile feedback (250) may be provided to the blueforce soldier (110,120) based on the blueforce-injury possibility. The tactile feedback may be provided via a tactile-feedback suit.

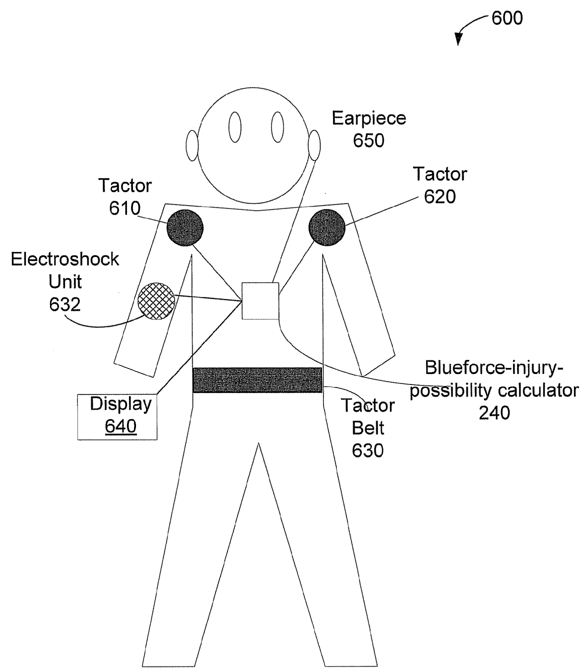

Figure 6

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Description

Field of the Invention

[0001] This invention generally relates to feedback to avoid friendly fire casualties, and specifically to providing tactile feedback when a weapon is trained on friendly personnel.

Background

[0002] Soldiers are frequently at risk of injury or death in battle. Unfortunately, some soldiers are injured or killed due to fire from friendly forces, herein referred to as "blueforce" fire. Blueforce fire may come from a variety of weapons, including rifles, artillery pieces, and missiles. The resulting casualties both scar the soldier and drain the morale of friendly forces and the soldier's family.

[0003] Figure 1 is an example scenario where blueforce-fire casualties could result. In the scenario of Figure 1, two blueforce soldiers 110 and 120 and three non-blueforce persons 130, 140, and 150 are shown near two buildings 160 and 170 and a blueforce-unit operation area 180. A "unit operation area" is a geographic location where a force unit, such as a platoon or company, is deployed. Blueforce soldier 110 is shown with a weapon 112 aimed away from other blueforce personnel, but blueforce soldier 120 is shown with a weapon 122 aimed in the general direction of blueforce soldier 110 and blueforce-unit operation area 180.

[0004] In this scenario, blueforce soldier 120 may be unaware of blueforce soldier 110 as building 160 blocks the view of blueforce soldier 120. The building 160 may also partially block the view blueforce soldier 120 has of blueforce-unit operation area 180. As such, if blueforce soldier 120 is startled by a non-blueforce person 130, 140, 150 or by an event in either building 160 or 170 (*e.g.*, an unexpected person exiting a building or an explosion) or if weapon 122 malfunctions in a fashion to fire as aimed, a blueforce-fire casualty could result.

[0005] Various schemes have been proposed to provide notifications or feedback about the possibility of friendly fire. Notification of friendly forces that depend on visual indicators alone may force a soldier to move his or her eyes to the visual indicator. Requiring a soldier to move his or her eyes may adversely affect the performance of the soldier, such as when aiming a weapon or driving a vehicle. Notifications of friendly forces that depend on audible indicators alone may also be hazardous in some situations, such as when an audible indicator alerts enemies to the location of the soldier. In some situations, visible and/or audible indicators may be difficult or even impossible for the soldier to detect, such as during a live-fire exercise or a battle.

SUMMARY

[0006] Embodiments of the present application include a method, system, and apparatus for providing feedback to blueforce personnel.

[0007] A first embodiment of the invention provides a method for providing feedback to a blueforce soldier. The blueforce soldier is armed with a weapon. A state of the weapon is determined. One or more blueforce personnel are located. A blueforce-injury possibility is determined, based on the state of the weapon and the locations of the one or more blueforce personnel. Feedback is determined, based on the determined blueforce-injury possibility. The determined feedback is provided to the blueforce soldier.

[0008] A second embodiment of the invention provides a blueforce-injury possibility calculator. The blueforce-injury possibility calculator has a user interface, a sensor interface, a processor, data storage, and machine-language instructions. The user interface includes at least one tactor. The sensor interface receives weapon-state information. The weapon-state information includes a direction of fire of the weapon and a firing-state of the weapon. The machine-language instructions are stored in the data storage and are executable by the processing unit to perform functions. The functions include determining an injury zone of the weapon, based on the weapon-state information, locating one or more blueforce personnel, determining a blueforce-injury possibility, based on the injury zone and the locations of the one or more blueforce personnel, determining feedback based on the determined blueforce-injury possibility, and providing the determined feedback via the at least one tactor.

[0009] A third embodiment of the invention provides a system. The system includes a weapon, a location system, a tactile-feedback suit, and a blueforce-injury calculator. The weapon includes at least one weapon sensor. The tactile-feedback suit includes at least one tactor. The blueforce-injury possibility calculator is configured to: (i) receive weapon-state information from the at least one weapon sensor, (ii) receive locations of blueforce personnel from the location system, (iii) determine an injury zone and a state of the weapon based on the weapon-state information, (iv) determine tactile feedback, based on the determined injury zone, the determined state of the weapon, and the received locations of blueforce personnel, and (v) provide the determined tactile feedback via the at least one tactor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various examples of embodiments are described herein with reference to the following drawings, wherein like numerals denote like entities, in which:

Figure 1 is an example scenario where blueforce-fire casualties could result;
Figure 2 is a block diagram showing an example blueforce-injury-possibility calculator and system, in accordance with embodiments of the invention;
Figure 3 is an example rifle with weapon sensors, in

accordance with embodiments of the invention;

Figure 4A shows an example of a blueforce-soldier with a weapon system and an injury zone of the weapon system, in accordance with embodiments of the invention;

Figure 4B shows another example of a blueforce-soldier with a weapon system and an injury zone of the weapon system, in accordance with embodiments of the invention;

Figure 5 is an example computing device, in accordance with embodiments of the invention;

Figure 6 is an example tactile-feedback suit, in accordance with embodiments of the invention; and

Figure 7 is a flowchart depicting an example method, in accordance with embodiments of the invention.

DETAILED DESCRIPTION

[0011] The instant application describes use of feedback mechanisms, including tactile feedback, to avoid friendly fire casualties. A blueforce soldier may be armed with a weapon that has one or more weapon sensors. The weapon sensors may provide information about a direction of fire and a firing state of the weapon. The direction of fire may be used to determine an injury zone, or zone of possible harm to other blueforce personnel. The firing state of the weapon may indicate if the weapon can harm other blueforce personnel. For example, the firing state of the weapon may be "unable to fire" if a safety of the weapon is engaged and/or if the weapon is unloaded. Otherwise the firing state of the weapon may be "able to fire".

[0012] The blueforce soldier may have a blueforce-injury-possibility calculator. The blueforce-injury-possibility calculator may determine the direction of fire, the firing state, and the injury zone of the weapon, based on the information from the weapon sensors. The blueforce-injury-possibility calculator may receive location information about one or more blueforce personnel. The blueforce-injury-possibility calculator may then determine a blueforce-injury possibility based on the injury zone and the location information. The blueforce-injury possibility may be zero if no blueforce personnel may be harmed by the weapon and may be non-zero if one or more blueforce persons may be harmed by the weapon (*i.e.,* located within the injury zone of the weapon with a firing state of "able to fire").

[0013] The blueforce-injury-possibility calculator may provide output in the form tactile feedback, including vibrotactile feedback, to the blueforce soldier if the blueforce-injury possibility is non-zero. The terms "output" and "feedback" are interchangeably used in this application.

[0014] Tactile feedback may effectively convey information. In particular, the use of vibrations as tactile feedback or "vibrotactile feedback" may be effective. Cholewiak and Collins indicate that tactile feedback patterns with low "communality" or few areas on the skin where feedback is common between patterns can be effectively distinguished. Roger W. Cholewiak and Amy Collins, "Vibrotactile Pattern Discrimination and Communality at Several Body Sites", Perception and Psychophysics, Vol. 57, No. 5, pp. 724-37, 1995. The use of more tactors may decrease the communality of the vibrotactile patterns provided and consequently increase the effectiveness of determining the pattern.

[0015] Vibrotactile feedback may be provided without requiring a person to shift their eyes to look at an indication, such as when visual feedback is provided. Further, vibrotactile feedback may be provided without causing light or sound emissions that could be seen or heard, respectively, by another person. Vibrotactile feedback may be felt in stimulus-rich environments, such as a battlefield or during a police raid, where visual and/or aural feedback may not be readily detected. One example of a wearable vibrotactile feedback system is manufactured by Anthrotronix, Inc. of Silver Spring, Maryland.

[0016] Vibrotactile feedback may be provided by one or more "tactors" which are devices designed to provide impulses, typically vibrations, to the skin of a user. An example tactor is the "C-2 Tactor" offered by Engineering Acoustics, Inc. of Casselberry, Florida. Unlike the other senses, the sensory inputs for the sense of touch are scattered throughout the body. Therefore, tactors may be attached to a garment, such as a uniform or tactile-feedback suit, to provide tactile feedback. A vibrotactile feedback system using several tactors is described in Aaron Bloomfield and Norman I. Badler, "A Low Cost Tactor Suit for Vibrotactile Feedback", University of Pennsylvania Department of Computer and Information Science, January 1, 2003, which is entirely incorporated herein by reference.

[0017] Varying levels and locations of tactile stimulation may be provided as tactile feedback. For example, a relatively high amplitude and/or high frequency vibrotactile pattern may indicate a nearby blueforce person or persons, whereas a lower amplitude and/or frequency vibrotactile pattern may indicate more distant blueforce person(s). Other forms of tactile feedback beyond vibrotactile feedback may be used as well. For examples, mild (and/or varying levels of) electrical shocks, chemical feedback, direct nerve stimulus, temperature changes, pressure, and/or painful tactile feedback may be used.

An Example Blueforce-Injury Possibility Calculator

[0018] Turning to the figures, Figure 2 is a block diagram 200 showing an example blueforce-injury-possibility calculator 240 connected and receiving inputs from a blueforce-location server 210, weapon-state information source 220, and a blueforce-command source 230 as inputs, and providing as possible outputs tactile output 250, aural output 260, and visible output 270, in accordance with embodiments of the invention. An example computing device that may be utilized as a blueforce-injury-possibility calculator is described below with reference to Figure 5.

[0019] The blueforce-injury-possibility calculator 240 may communicate with blueforce-location server 210 about the location of one or more blueforce persons. An example blueforce-location server is the Global Personnel Recovery System (GPRS) provided by Innovative Solutions, International of Vienna, VA. However other blueforce-location servers are available as well. The blueforce-location server 210 may comprise multiple physical devices as well, such as multiple processors each of which is performing as a server and/or each processor performing one or more server-related tasks.

[0020] The blueforce-location server 210 may provide location information gathered from location devices worn or carried by each blueforce person. Location information may be gathered from one or more location devices mounted on a vehicle, such but not limited to a car, personnel carrier, or tank. The location devices may use one or more location techniques, such as but not limited to techniques based on Global Positioning System (GPS) technology, triangulation of radio waves, and/or dead reckoning. A location device may provide an update of the location of one or more blueforce persons periodically, as requested, or using some other update strategy. The blueforce-location server 210 may provide location information periodically, upon request, and/or using some other strategy, to blueforce-injury-possibility calculator 240.

[0021] Each location device may provide one or more location notifications to indicate a location. The one or more location notifications also may indicate an identifier of a blueforce person (*e.g.*, serial number), an identifier of a unit of the blueforce person (*e.g.*, Company A, 3rd Platoon), and/or time/date information. And other information may be part of a location notification as well.

[0022] The blueforce-injury-possibility calculator 240 may be equipped with a location device. As such, the blueforce-injury-possibility calculator 240 may provide location information, including location notifications, to the blueforce-location server 210. The location information provided by the blueforce-injury-possibility calculator 240 may enable the blueforce-location server to track the location of the soldier or other user of the blueforce-injury-possibility calculator 240.

[0023] The blueforce-location server 210 may provide location information of individual blueforce persons, such as the blueforce soldiers shown in Figure 1, and/or blueforce units, such as the blueforce-unit operation area also shown in Figure 1. The blueforce-location server 210 may provide location information about blueforce units by determining a unit operation area for the blueforce unit based on the location notifications received from soldiers in the blueforce unit. For example, if an infantry company is deployed at a given area, location notifications from one or more soldiers in the infantry company may be received from the given area. The blueforce-location server 210 and/or the blueforce-injury-possibility calculator 240 may determine that the given area is an operation area of the infantry company. One process to determine the given area is an operation area is (i) determine the number of soldiers assigned to the unit (*e.g.*, the infantry company) in the given area, (ii) compare the number of soldiers to a threshold, and (iii) determine the given area is an operation area if the number of soldiers exceeds the threshold. Other processes for determining an operation area are possible as well.

[0024] The blueforce-location server 210 and/or the blueforce-injury-possibility calculator 240 may maintain location information about multiple blueforce units. The blueforce-location server 210 may maintain location information about blueforce personnel across service boundaries (*e.g.*, both Army and Marine units), across command boundaries, and/or across national boundaries (*e.g.*, provide information about both United States and allied troops operating in the same area). Also, the blueforce-injury-possibility calculator 240 may receive location information from multiple blueforce-location servers 210 and determine location information from some or all of the blueforce-location servers 210. In particular, the blueforce-injury-possibility calculator 240 may filter location information based on geographic location, such as determining the locations of all blueforce personnel within 2000 meters of the blueforce-injury-possibility calculator 240. The blueforce-injury-possibility calculator 240 may determine its own location via information from one or more of the blueforce-location servers 210 and/or via a location device aboard the blueforce-injury-possibility calculator 240.

[0025] The blueforce-injury-possibility calculator 240 may receive weapon-state information from one or more weapon-state information sources 220. The weapon-state information source 220 may provide information about a type of a weapon, a direction of fire of the weapon, and a state of the weapon. An example weapon capable of including a weapon-state information source 220 is described below with reference to Figure 3.

[0026] The blueforce-injury-possibility calculator 240 may receive input from a blueforce-command source 230. The blueforce-command source 230 may communicate information from the chain of command of the user of the blueforce-injury-possibility calculator 240. For example, the blueforce-command source 230 may provide information about blueforce-unit operations or intelligence about enemy movements.

[0027] The blueforce-command source 230 may provide commands to the blueforce-injury-possibility calculator 240. The commands may be directed to one or more blueforce-injury-possibility calculators 240, such as commands directed to a particular blueforce-injury-possibility calculator 240 (*i.e.,* to a particular soldier), to all blueforce-injury-possibility calculators 240 in a given geographical area, and/or all blueforce-injury-possibility calculators 240 associated with particular unit(s) (*e.g.*, all blueforce-injury-possibility calculators associated with Bravo Company). In particular, the blueforce-command source 230 may provide commands about output options of the blueforce-injury-possibility calculator 240. For example, the blueforce-command source 230 may provide commands to enable tactile output 250 and/or inhibit aural output 260 from all blueforce-injury-possibility calculators 240 in a blueforce-unit operation area.

[0028] The blueforce-injury-possibility calculator 240 may communicate with the entities shown in Figure 2 via a network. While the blueforce-location server 210, the weapon-state information source 220, and the blueforce-command source 230 are described as "inputs" above, they may also receive information from the blueforce-injury-possibility calculator 240 as well. For example, the blueforce-location server 210 and/or the blueforce-command source 230 may receive input about a weapon-state via the blueforce-injury-possibility calculator 240. As another example, the weapon-state information source 220 may receive input from the blueforce-injury-possibility calculator 240 to control a weapon (*e.g.*, engage a safety switch of the weapon).

[0029] Many other types of information may be passed from the blueforce-injury-possibility calculator 240 to the blueforce-location server 210, the weapon-state information source 220, and/or the blueforce-command source 230 as well. For example, information may be passed to the blueforce-injury-possibility calculator about the locations of special features (particularly non-military) of a location, such as refugee camps, locations of villages/towns, culturally sensitive sites, neutral/no-fire zones, locations where civilians may be wandering unexpectedly (*e.g.*, campgrounds or national parks), or gatherings of people. The blueforce personnel may then attempt to accommodate the non-military features of the location, such as changing a firing rate of a weapon (i.e., change to single shot instead of full automatic while near a refugee camp), changing a direction of travel of the blueforce personnel, and/or change the choice weapons and/or ammunition used while at or near those locations.

[0030] The blueforce-injury-possibility calculator 240 may use a network-communication interface, such as described below with respect to Figure 5, to communicate with the blueforce-location server 210, the weapon-state information source 220, the blueforce-command source 230, and the output devices 250-270 shown in Figure 2.

[0031] The blueforce-injury-possibility calculator 240 may provide one or more outputs. The one or more outputs may indicate the possibility of harming one or more blueforce personnel, as well as an indication of potential harm to the one or more blueforce personnel. Figure 2 shows blueforce-injury-possibility calculator 240 connected to tactile output 250, aural output 260, and visible output 270. An example tactile output 250 is a tactile-feedback suit, which is described below with reference to Figure 5.

[0032] The aural output 260 may provide sounds, such as tones, beeps, vocalizations, and other sounds, as directed by the blueforce-injury-possibility calculator 240. The aural output 260 may be a speaker or other device capable of producing sounds, such as described below with reference to the output unit of Figure 5.

[0033] The visible output 270 may provide visible indications, such as alphanumeric characters, shapes, colors, and other visible indications, as directed by the blueforce-injury-possibility calculator 240. The visible output 270 may be a LCD, LED, or other display capable of producing textual and/or graphical output, such as described below with reference to the output unit of Figure 5.

[0034] Similarly, the tactile output 250, the aural output 260, and the visible output 270 may provide input to the blueforce-injury-possibility calculator 240 as well, such as diagnostic information or additional information depending on the exact type of output device(s) used (*e.g.*, a visible output device that also has a camera may provide video input to the blueforce-injury-possibility calculator 240 or the aural output 260 may comprise a microphone for speech input). Many other types of information may be passed to the blueforce-injury-possibility calculator 240 from the tactile output 250, aural output 260, and visible output 270 as well.

[0035] As another output, the blueforce-injury-possibility calculator 240 may provide an indication of potential harm to one or more blueforce personnel that may be harmed by the user of the blueforce-injury-possibility calculator 240. For example, if the blueforce-injury-possibility calculator 240 determines that Private Pyle may harm Sergeant Hartmann, the blueforce-injury-possibility calculator 240 used by Private Pyle may send an indication of potential harm to Sergeant Hartmann. The indication of potential harm may include the source of the harm (*e.g.*, Private Pyle), the location of the blueforce-injury-possibility calculator 240 sending the indication, and/or a time of the indication. The blueforce-injury-possibility calculator 240 may send the indication of potential harm directly to a blueforce-injury-possibility calculator 240 used by blueforce personnel that may be harmed (*i.e.*, assuming multiple blueforce-injury-possibility calculators are connected via a wired or wireless LAN/WAN) or indirectly via a network entity, such as a blueforce-location server 210 or the blueforce-command source 230.

An Example Weapon

[0036] Figure 3 is an example weapon system 300 with weapon sensors 350, 360, and 370, in accordance with embodiments of the invention. The example weapon system 300 is shown in Figure 3 is a rifle with a stock 310, a barrel 320, a muzzle 330 of the barrel 320, and a trigger 340. The rifle may be operated by a soldier or other user by loading the rifle with one or more rounds (bullets), holding the stock 310 next to the shoulder of the user, aiming the rifle in the direction of the muzzle 330, and pulling the trigger 340 to fire the loaded rounds.

[0037] The weapon system 300 may be equipped with a safety 342. The safety 342 may be engaged or not engaged. When the safety 342 is engaged, the weapon system 300 may be prohibited from firing even if the weapon system 300 is loaded and the trigger 340 is pulled. However, when the safety 342 is not engaged, the weapon system 300 may be able to fire loaded rounds when the trigger 340 is pulled.

[0038] The weapon-state sensor 350 may be provide data used to determine a "firing state" of the weapon system 300. The firing state of the weapon system 300 is the ability of the weapon to immediately fire; *e.g.*, the firing state of the weapon system 300 may be "able to fire" or "unable to fire". The firing state of the weapon system 300 may depend on the state of the safety 342 and a number of rounds loaded into weapon system 300. For example, the weapon system 300 may have a firing state of "able to fire" if (a) the safety is not engaged and (b) one or more rounds are loaded in the weapon system. Otherwise, the firing state may be "unable to fire". Other methods for determining and/or expressing the firing state are possible as well. The weapon-state sensor 350 may provide data such as the state of the safety 342 and/or the number of rounds loaded in the weapon 300. The data provided by the weapon-state sensor 350 may, in addition or instead of the number of rounds, comprise a loaded/unloaded indicator of the weapon 300. The loaded/unloaded indicator may indicate "unloaded" if no rounds were loaded into the weapon 300 or indicate "loaded" if one or more rounds were loaded into the weapon 300.

[0039] The weapon-state sensor 350 may also be able to determine if a round is "chambered" or loaded into the weapon system 300 and also ready for immediate fire by the weapon system 300. In that case, the firing state may be "able to fire" if (a) the safety is not engaged and (b) a round is chambered. Otherwise, the firing state may be "unable to fire". Use of a weapon-state sensor 350 that can determine when a round is chambered permits the distinction of a weapon system that is loaded but unable to fire since a round has not yet been chambered.

[0040] The direction of fire of the weapon system 300 may be determined based on data from the back sensor 360 and/or front sensor 370. At any given time, the back sensor 360 and the front sensor 370 may each provide their current position. Preferably, the back sensor 360 and/or the front sensor 370 each provide their current position using Global Positioning System (GPS) technology or a similar technology. The current position of a sensor may be indicated in three dimensions using a coordinate system (*e.g.*, a two or three dimensional Cartesian coordinate system), as a latitude, longitude, and elevation, via map coordinates, or by use of another way of indicating a current position. Timing information may be provided with the current position information as well, *e.g.*, indicating the position of a sensor at 1100 hours on June 7, 2008. The location of the weapon system 300 may be determined to be the current position of either the front sensor 370 or the back sensor 360.

[0041] The back sensor 360 and/or the front sensor 370 may provide their respective current positions to a blueforce-injury-possibility calculator or similar device to determine the direction of fire of the weapon. For example, suppose the back sensor indicates a position of [10,10,10] in a given [x,y,z] coordinate system at a given time t and the front sensor indicates a position of [10,12,10] in the same [x,y,z] coordinate system at time t. For example, a relative position of the weapon of [0,2,0] may be determined by subtracting the front sensor position from the rear sensor position. The relative position of the weapon may indicate a direction of fire, *e.g.*, the relative position of [0,2,0] indicating the weapon is aimed solely in the y-direction. The relative position may be used to determine a targeting solution of the weapon, such as the azimuth, direction, and/or elevation values for the weapon. The relative position and/or the direction of fire may be determined by other means as well, such as, but not limited to, inertial sensors, accelerometers, electronic compasses, gyroscopes (including ring laser gyroscopes), and/or optical location devices.

[0042] The example weapon system 300 shown in Figure 3 is a rifle, but other weapon systems may utilize weapon sensors similarly. That is, other types of weapons may utilize one or more sensors to provide weapon-state information (and thus act as a weapon-state information source 220). For example, similar sensors to the back sensor 360 and front sensor 370 (or the same sensors) may be added to larger weapons, such as artillery pieces or missile launchers, to determine a direction of fire of the larger weapon. A similar weapon-state sensor to weapon-state sensor 370 may be used to determine if a shell is or is not loaded into such a larger weapon.

Examples of Injury Zones

[0043] Figure 4A shows an example of a blueforce-soldier 400 with a weapon system 410 and an injury zone 420 of the weapon system 410, in accordance with embodiments of the invention. An "injury zone" of a weapon system may be determined based on a direction of fire. Figure 4A shows an injury zone 420 with dashed lines and defined by a left extent 414, a right extent 416, and an outer extent 418 oriented around a direction of fire (DOF) 412. The direction of fire 412 may be determined as described above with reference to Figure 3.

[0044] Once the direction of fire 412 is determined, the left extent 414 and right extent 416 of the injury zone 420 may be determined. The left extent 414 and right extent 416 indicate the likely-leftmost direction of fire and likely-rightmost direction of fire, respectively, if the weapon system 410 is discharged when initially aimed along the direction of fire 412. That is, if the weapon system 410 is discharged while aimed along the direction of fire 412, the discharged round will likely travel along a path somewhere between the left extent 414 and the right extent 416. The injury zone 420 may also depend on the location of the weapon system 410.

[0045] The left extent 414 and/or the right extent 416 of the injury zone 420 may be determined with respect to one or more "weapon-system movement" angles. Figure 4A shows the left extent 414 defined with respect to an angle of L° and the right extent 416 defined with respect to an angle of R°. Note that the angle L° may or may not be the same as the angle R°. For example, L° may not be the same as R° if the blueforce-soldier 400 tends to move the weapon system 410 to the left (or right) while firing. The angles L° and/or R° may also depend on the situation of the blueforce soldier 400; for example, L° and/or R° may be smaller when the blueforce soldier 400 is deployed with many other soldiers simultaneously (*i.e.,* with his/her unit) as the risk of blueforce-fire injuries has increased due to the higher density of blueforce personnel.

[0046] The angles L° and/or R° may further depend on meteorological conditions, such as temperature, humidity, and wind - for example, if a wind is blowing in the direction from the blueforce-unit operation area 440 toward the blueforce soldier 434, a round fired from the weapon system 410 may be blown in that wind toward the right extent and as such, R° may be greater than L°. Similarly, R° may be less than L° if the wind blows in the direction from the blueforce soldier 434 toward the blueforce-unit operation area 440.

[0047] The outer extent 418 of the injury zone 420 may be the farthest distance from the muzzle of the weapon system 410 where a person may be injured by a round fired from weapon system 410. The outer extent 418 may be based on the type of the weapon system 410. For example, if the weapon system 410 may fire rounds that travel 1000 meters, the outer extent 418 may be farther from the weapon system 410 than if the weapon system 410 can fire rounds that travel 900 meters. The outer extent may be based on the type of rounds fired by the weapon system 410. For example, if the weapon system 410 is loaded with rounds that may travel 700 meters, the outer extent 418 may be farther from the weapon system 410 than if the weapon system 410 is loaded with rounds that travel 650 meters.

[0048] The outer extent 418 may further depend on meteorological conditions, such as temperature, humidity, and wind. For example, if a wind is blowing in the direction from the blueforce-soldier 400 toward the blueforce soldier 434, a round fired from weapon system 410 may be blown in that wind farther than if no wind was blowing, and as such, the outer extent 418 may be increased due to the wind. Similarly, the outer extent 418 may be decreased when the wind blows in the direction from the blueforce soldier 434 toward blueforce soldier 400

[0049] Figure 4B shows another example of a blueforce-soldier 450 with a weapon system 460 and an injury zone 470 of the weapon system 460, in accordance with embodiments of the invention. The determination of the injury zone may depend on the type of weapon system. Figure 4B shows a blueforce soldier 450 operating a mortar as the weapon system 470. The weapon system 460 may fire rounds that generally land in a circular or elliptical region some distance from the weapon system 460. Figure 4B shows the injury zone 470 as a circular region some distance from weapon system 460. The injury zone 470 may be determined by a mathematical model, such as the well-known ballistics equations of motion, based on the direction of fire or azimuth, elevation, and location of the weapon system 470. Also, as described above with respect to Figure 4A, the injury zone 480 may be determined based on the type of weapon system and/or the types of rounds fired by the weapon system. For example, if the weapon system 470 is an artillery piece or a tank, the injury zone may have a different shape and/or size than the injury zone for a rifle or a mortar. Also, the size and shape of the injury zone of the weapon system 470 may vary over time. For example, if the weapon system 470 is firing rounds with more explosives than previously-fired rounds, the injury zone 480 may be enlarged and/or have a different shape compared to an injury zone determined for the previously-fired rounds.

[0050] A blueforce-injury possibility may be determined based on the location(s) of blueforce person(s) and/or the state of a weapon system. Figure 4A shows a blueforce soldier 430 partially in the injury zone 420 of the weapon system 410. As the blueforce soldier 430 is in the injury zone 420, the blueforce soldier 430 may risk injury if the weapon system 410 is fired, and thus the blueforce-injury possibility to the blueforce soldier 430 may be non-zero. However, if the weapon state of the weapon system 410 is "unable to fire", the blueforce-injury possibility to the blueforce soldier 430 may be zero. Also, the blueforce soldiers 420 and 440 are not at risk of injury from weapon system 410 as they are outside the injury zone 420. Further, any blueforce personnel operating in the blueforce-unit operation area 450 are also outside the injury zone 420, and thus not at risk of injury from weapon system 410.

[0051] The determination of the blueforce-injury possibility may depend on one or more settings, such as user settings, of the blueforce-injury-possibility calculator 240. One of the settings of the blueforce-injury-possibility calculator 240 may indicate a operational mode to the blueforce-injury-possibility calculator 240. Example operational modes are an "active" mode, a "blueforce-radar" mode, and/or an "inactive mode." The active mode may indicate that the blueforce-injury-possibility calculator 240 determines the blueforce-injury possibility based on the injury zone and the firing state of a weapon system. The blueforce-radar mode may indicate that the blueforce-injury possibility is based only on the injury zone of the weapon system - as such, while in blueforce-radar mode, the blueforce-injury possibility treats the weapon system as a pointer to locate blueforce personnel. The weapon system can remain unloaded while in blueforce-radar mode, as the firing state is ignored, and thus reduce the risk to blueforce personnel while the weapon system is maneuvered in an attempt to find blueforce personnel. The inactive mode may indicate the blueforce-injury-possibility calculator 240 is not being used and so the blueforce-injury-possibility calculator 240 may not provide any determination of the blueforce-injury possibility regardless of the injury zone and/or the firing state.

[0052] For example, if the blueforce soldier 400 is using the blueforce-injury possibility calculator mode in the active mode, the blueforce-injury-possibility calculator 240 provides feedback based on a blueforce-injury possibility to a user, including taking into account the firing state of a weapon system 410 of the blueforce soldier 400. As such, no feedback will be provided to the blueforce soldier 400 if weapon system 410 is unloaded or has the safety engaged. However, while in blueforce-radar mode, the blueforce-injury-possibility calculator 240 does not take into account the firing state of the weapon system 410, and thus provides feedback to the blueforce soldier 400 based only on the injury zone of the weapon system 410, enabling the blueforce soldier 400 to locate the blueforce soldiers 430 and 432 by maneuvering the weapon system 410 while the weapon system 410 is not able to fire (*e.g.*, while weapon system 410 is unloaded or has the safety is engaged).

[0053] Figure 4B shows a blueforce soldier 480 in the injury zone 470 of weapon system 460. Also, part of the blueforce-unit operation area 490 overlaps the injury zone 470. Therefore, if the weapon system 460 fires, the blueforce soldier 480 and any blueforce personnel in the portion of the blueforce-unit operation area 490 that overlaps the injury zone 470 may have a non-zero blueforce-injury possibility.

An Example Computing Device

[0054] Figure 5 is a block diagram of an example computing device 500, comprising a processing unit 510, data storage 520, a user interface 530, and a network-communication interface 560, in accordance with embodiments of the invention. A computing device 500 may be a desktop computer, laptop or notebook computer, personal data assistant (PDA), mobile phone, embedded processor, or any similar device that is equipped with a processing unit capable of executing computer instructions that implement at least part of the herein-described method 700 of Figure 7 and/or herein-described functionality of a blueforce-injury-possibility calculator.

[0055] The processing unit 510 may include one or more central processing units, computer processors, mobile processors, digital signal processors (DSPs), microprocessors, computer chips, and similar processing units now known and later developed and may execute machine-language instructions and process data.

[0056] The data storage 520 may comprise one or more storage devices. The data storage 520 may include read-only memory (ROM), random access memory (RAM), removable-disk-drive memory, hard-disk memory, magnetic-tape memory, flash memory, and similar storage devices now known and later developed. The data storage 520 comprises at least enough storage capacity to contain machine-language instructions 522 and data structures 524.

[0057] The machine-language instructions 522 and the data structures 524 contained in the data storage 520 include instructions executable by the processing unit 510 and any storage required, respectively, to perform some or all of the functions of a herein-described blueforce-injury-probability calculator, a blueforce location server, a weapon-state information source, a blueforce-command source, and/or to perform some or all of the procedures described in method 700.

[0058] The user interface 530 may comprise an input unit 540 and/or an output unit 550. The input unit 540 may receive user input from a user of the computing device 530. The input unit 540 may comprise a keyboard, a keypad, a touch screen, a computer mouse, a track ball, a joystick, and/or other similar devices, now known or later developed, capable of receiving user input from a user of the computing device 500.

[0059] The input unit 540 may also comprise a location device. The location device may determine the location of the computing device 500 via one or more location technologies, such as Global Position System (GPS), triangulation of electromagnetic waves, dead reckoning, or by another location technology.

[0060] The output unit 550 may provide output to a user of the computing device 500. The output unit 550 may comprise a visible output device 552, such as one or more cathode ray tubes (CRT), liquid crystal displays (LCD), light emitting diodes (LEDs), displays using digital light processing (DLP) technology, printers, light bulbs, and/or other similar devices, now known or later developed, capable of displaying graphical, textual, and/or numerical information to a user of computing device 500. The output unit 550 may alternately or additionally comprise one or more aural output devices 554, such as a speaker, speaker jack, audio output port, audio output device, earphones, and/or other similar devices, now known or later developed, capable of conveying sound and/or audible information to a user of computing device 500. The output unit 550 may also comprise one or more tactile output devices 556, such as a tactor, a tactile buzzer, tactile cue, and/or other similar devices, now known or later developed, capable of providing tactile information to a user of computing device 500. The output unit 550 may also comprise part or all of a tactile-feedback suit described below with reference to Figure 6.

[0061] The network-communication interface 560 is configured to send and receive data and may include a wired-communication interface and/or a wireless-communication interface. The wired-communication interface, if present, may comprise a wire, cable, fiber-optic link or similar physical connection to a wide area network (WAN), a local area network (LAN), one or more public data networks, such as the Internet, one or more private data networks, or any combination of such networks. The wireless-communication interface, if present, may utilize an air interface, such as an IEEE 802.11 (*e.g.*, Wi-Fi) and/or IEEE 802.16 (*e.g.,* WiMax) interface to a WAN, a LAN, one or more public data networks (*e.g.*, the Internet), one or more private data networks, or any combination of public and private data networks.

An Example Tactile-Feedback Suit

[0062] Figure 6 is an example tactile-feedback suit 600 shown with tactors 610 and 620, a tactor belt 630, a display 640, and an earpiece 650 connected to blueforce-injury-possibility calculator 240 in accordance with embodiments of the invention. The tactile-feedback suit 600 may provide tactile stimulation or feedback to the wearer via one or more tactors. Figure 6 shows the tactile-feedback suit 600 with two tactors 610 and 620. More or fewer tactors may be part of the tactile-feedback suit 600. The tactors 610 and 620 are shown on the shoulders of the tactile-feedback suit 600. However, the tactile-feedback suit may have tactors on any portion of the tactile-feedback suit 600, including (but not limited to), the head, legs, arms, hands, trunk, back, sides, and/or feet of the tactile-feedback suit 600. Also, the tactors may be arranged in one or more bands or belts, such as the tactor belt 630. Figure 6 shows the tactile-feedback suit 600 as a separate suit, but the components of the tactile-feedback suit 600 may be part of or attached to another garment, such as a uniform, as well.

[0063] Each tactor may provide various levels of stimulation to the wearer of the tactile-feedback suit 600. Each tactor may be directed to provide stimulation of varying frequencies, durations, amplitudes, and/or curve shapes (*e.g.*, square waves or sinusoidal waves). The use of different frequencies, durations, amplitudes, and/or curve shapes may provide tactile feedback about the relative locations of and/or risks to blueforce personnel. For example, a low-amplitude and/or low-frequency burst of stimulation from one or more tactors may indicate that blueforce personnel are relatively far away or are at low risk of injury. However, a high-amplitude and/or high-frequency burst of stimulation may indicate blueforce personnel are relatively close and/or at high risk of injury. As another example, the duration of the burst of stimulation may be tied to the duration of the risk to blueforce personnel; that is, the burst may last as long as blueforce personnel are at risk due to blueforce fire from the wearer of the tactile-feedback suit 600.

[0064] The use of tactors on various portions of the body may provide additional feedback. For example, suppose the tactile-feedback suit 600 has tactors on the front, back, and on each side. If blueforce personnel in front or behind the wearer of the tactile-feedback suit 600 are at risk, the tactors on the front or the back, respectively, of tactile-feedback suit 600 may be activated to provide a burst of stimulation. Similarly, if the blueforce personnel at risk are on the right (or left) of the wearer of the tactile-feedback suit 600, tactors on the right side (or the left side) may be activated.

[0065] Use of other types of tactile feedback beyond vibrotactile feedback may be used with tactile-feedback suit 600. Figure 6 shows the tactile-feedback suit with an electroshock unit 632. The electroshock unit 632 may be configured to provide electric shocks to the wearer of the tactile-feedback suit 600. As with tactors, one or more electroshock units may be directed to provide electric shock stimulation of varying frequencies, durations, amplitudes, and/or curve shapes. Providing other types of tactile stimulation devices (i.e.., other than tactors 610-620, tactor belt 630, and electroshock unit 632) with the tactile-feedback suit 600 may provide other types of tactile feedback to the wearer of the tactile-feedback suit 600, such as, but not limited to, chemical feedback, direct nerve stimulus, temperature changes, pressure, and/or painful tactile feedback. Further, different types of tactile feedback may be provided depending on the situation, such as use of vibrotactile feedback for relatively low risks to blueforce personnel and electric shocks and/or painful feedback for relatively high risks to blueforce personnel.

[0066] The tactile-feedback suit may provide support for visible and/or aural feedback as well. Then, the blueforce-injury-possibility calculator 240 may instruct tactile-feedback suit 600 to provide visible and/or aural feedback in addition to tactile feedback. Figure 6 shows the tactile-feedback suit 600 equipped with a display 640 and an earpiece 650 for visible and aural feedback, respectively. The visible and/or aural feedback may provide additional information about the location of blueforce personnel and/or units. Further, visible and/or aural feedback may be provided if the capacity for tactile feedback is reduced or zero, such as when the tactors 610 and 620 and/or tactor belt 630 are inoperable.

An Example Method for Providing Feedback to a Blueforce Soldier

[0067] Figure 7 is a flowchart depicting an example method 700, in accordance with embodiments of the invention. Method 700 provides feedback to a blueforce soldier armed with a weapon. It should be understood that each block in this flowchart and within other flowcharts presented herein may represent a module, segment, or portion of computer program code, which includes one or more executable instructions for implementing specific logical functions or steps in the process. Alternate implementations are included within the scope of the example embodiments in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the described embodiments.

[0068] At block 710, a blueforce-injury-possibility calculator is initialized. The blueforce-injury-possibility calculator may be initialized based on user settings. For example, the user of the blueforce-injury-possibility calculator may enable, disable, and/or adjust tactile, aural, and/or visible feedback. The user settings may comprise feedback parameters. The feedback parameters may include the frequency, duration, amplitude and/or curve shapes of tactile and/or aural feedback. The user settings may include a maximum value, a minimum value, and/or an enabled/disabled status for each feedback parameter. The user settings may indicate a mode of the blueforce-injury-possibility calculator, such as an active mode, an inactive mode, and/or a blueforce-radar mode. For visible feedback, frequency, duration, color, and/or size user settings and/or feedback parameters may be provided. Many other user settings and/or feedback parameters are possible as well.

[0069] The feedback parameters and/or the user settings may be set by a blueforce-command source. The feedback parameters and/or the user settings may be "locked", that is, unable to be changed by the user of the blueforce-injury-possibility calculator. In particular, locked feedback parameters and/or user settings may be provided as commands from the blueforce-command source to the user of the blueforce-injury-possibility calculator.

[0070] User settings and/or feedback parameters may be determined by one or more algorithms. For example, a "location direction" algorithm may set tactile feedback parameters to indicate a relative location of any blueforce personnel in the injury zone of a weapon of the user of the blueforce-injury-possibility calculator. The location direction algorithm may set: (a) tactile-duration feedback parameter(s) to provide feedback while the blueforce personnel are in the injury zone and (b) tactile-frequency and/or tactile-amplitude parameters to be proportional to the distance to the blueforce personnel in the injury zone. The location direction algorithm may make similar settings for aural and/or visible feedback parameters as well. Another example is an algorithm that generates tactile-feedback patterns via a number of tactors with low communality and consequently increases effectiveness in distinguishing between the tactile-feedback patterns. Some or all of the herein-described user settings and/or feedback parameters may be hardcoded as well.

[0071] At block 720, a state of a weapon is determined. The state of the weapon may comprise a direction of fire. The direction of fire may be determined based on data from one or more weapon sensors attached to the weapon. In particular, the direction of fire may be determined by location data from a front location sensor and a rear location sensor. A relative position of the weapon may be determined by subtracting location data from the front location sensor from location data from the rear location data (or vice versa). The direction of fire may be determined based on the relative position of the weapon.

[0072] The state of the weapon may comprise an injury zone. The injury zone may be based on the direction of fire of the weapon, the type of weapon, and/or the type of rounds used by the weapon. The size and/or shape of the injury zone may vary over time. The injury zone may be wedge-shaped, elliptical, circular, or of another shape altogether.

[0073] The state of the weapon may comprise a firing state of the weapon. The firing state of the weapon may be expressed as "able to fire" or "unable to fire". The firing state may comprise a state of a safety of the weapon (*e.g.*, engaged or not engaged) and/or a number of rounds loaded in the weapon system. The firing state may be determined based on data from one or more weapon sensors. The one or more weapon sensors may provide data on the state of the safety, the number of rounds loaded in the weapon system and/or a loaded/unloaded indicator.

[0074] At block 730, one or more blueforce personnel are located. The blueforce personnel may be located by the blueforce-injury-possibility calculator based on location information received from one or more blueforce-location servers. The blueforce-injury-possibility calculator may filter the received location information, such as filtering the received location information based on the location of the blueforce-injury-possibility calculator.

[0075] At block 740, a blueforce-injury possibility is determined based on the state of the weapon and the locations of the one or more blueforce personnel. One sequence of operations to determine the blueforce-injury possibility is:

(i) Determine the firing state of the weapon. If the firing state of the weapon is "unable to fire", then the blueforce-injury possibility may be determined to be zero as the weapon cannot harm any blueforce personnel. Proceed on to operation (ii) if the firing state of the weapon is "able to fire".
(ii) Determine the injury zone of the weapon.
(iii) Determine the location(s) of blueforce personnel.
(iv) Determine if the locations of any blueforce personnel are partially or completely within the injury zone of the weapon. If no blueforce personnel are within the injury zone of the weapon, then the blueforce-injury possibility may be determined to be zero. Proceed on to operation (v) if blueforce personnel are in the injury zone of the weapon.
(v) Determine a non-zero blueforce-injury possibility. For example, the blueforce-injury possibility to a blueforce person may be proportional to the relative location of a blueforce person and the weapon. The blueforce-injury possibility may be determined based on stored data, such as a database or lookup table. The stored data may be indexed by the relative location of the blueforce person, the type of the weapon, and/or the type of rounds loaded into the weapon.

[0076] Note that other sequences of operations may be used to determine the blueforce-injury possibility, including performing the above mentioned operations in a different sequence.

[0077] At block 750, feedback is determined based on the determined blueforce-injury possibility. For example, the frequency and/or the amplitude of the feedback (*e.g.*, tactile feedback) may be directly proportional to the blueforce-injury possibility. Also the curve shape of the feedback may be determined based on the determined blueforce-injury possibility, such as use of square-wave feedback if the blueforce-injury possibility exceeds a threshold and use of sinusoidal-wave feedback if the blueforce-injury possibility does not exceed the threshold.

[0078] At block 760, the determined feedback is provided to the blueforce soldier. The determined feedback may be provided via an output unit comprising visible, aural, and/or tactile output devices. The tactile output device(s) may include one or more tactors and may include a tactile-feedback suit. After performing block 760, the method 700 may proceed to block 720. As such, if the state of the weapon and/or the locations of blueforce personnel change, the determined feedback may change between iterations of method 700.

Conclusion

[0079] Exemplary embodiments of the present invention have been described above. Those skilled in the art will understand, however, that changes and modifications may be made to the embodiments described without departing from the true scope and spirit of the present invention, which is defined by the claims. It should be understood, however, that this and other arrangements described in detail herein are provided for purposes of example only and that the invention encompasses all modifications and enhancements within the scope and spirit of the following claims. As such, those skilled in the art will appreciate that other arrangements and other elements (*e.g.* machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead, and some elements may be omitted altogether.

[0080] Further, many of the elements described herein are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location, and as any suitable combination of hardware, firmware, and/or software.

Claims

1. A blueforce-injury possibility calculator, comprising:

a user interface;
a sensor interface for receiving weapon-state information, wherein the weapon-state information comprises a direction of fire of a weapon and a firing-state of the weapon;
a processor;
data storage; and
machine-language instructions stored in the data storage and executable by the processing unit to perform functions including:

determining an injury zone of the weapon based on the weapon-state information,
locating one or more blueforce personnel,
determining a blueforce-injury possibility based on the injury zone and the locations of the one or more blueforce personnel,
determining feedback based on the blueforce-injury possibility, and
providing the feedback.

2. The blueforce-injury possibility calculator of claim 1, wherein providing the feedback comprises providing tactile feedback.

3. The blueforce-injury possibility calculator of claim 2, wherein providing tactile feedback comprises providing tactile feedback about the location of the one or more blueforce personnel.

4. The blueforce-injury possibility calculator of claim 1, wherein determining feedback comprises determining a level of feedback to be provided based on a comparison of the blueforce-injury possibility to at least one blueforce-injury possibility threshold.

5. The blueforce-injury possibility calculator of claim 4, wherein determining a level of feedback to be provided comprises determining tactile feedback is to be provided based on determining the blueforce-injury possibility is greater than a first blueforce-injury possibility threshold and wherein the determined level of tactile feedback to be provided is proportional to the blueforce-injury possibility.

6. The blueforce-injury-possibility calculator of claim 10, wherein the weapon-state information comprises a direction of fire of the weapon.

7. The blueforce-injury-possibility calculator of claim 10, wherein the weapon-state information comprises a type of weapon.

8. The blueforce-injury-possibility calculator of claim 1, wherein the user interface comprises a tactor.

9. The blueforce-injury-possibility calculator of claim 1, wherein determining a blueforce-injury possibility depends on a mode of the blueforce-injury possibility calculator.

10. The blueforce-injury-possibility calculator of claim 9, wherein the mode of the blueforce-injury-possibility calculator comprises a blueforce-radar mode and an active mode, and
wherein determining the blueforce-injury possibility comprises: (1) determining a blueforce-injury possibility based on the injury zone while the blueforce-injury-possibility calculator is in the blueforce-radar mode and (2) determining a blueforce-injury possibility based on the injury zone and a firing state of the weapon while the blueforce-injury-possibility cal-

culator is in the active mode.

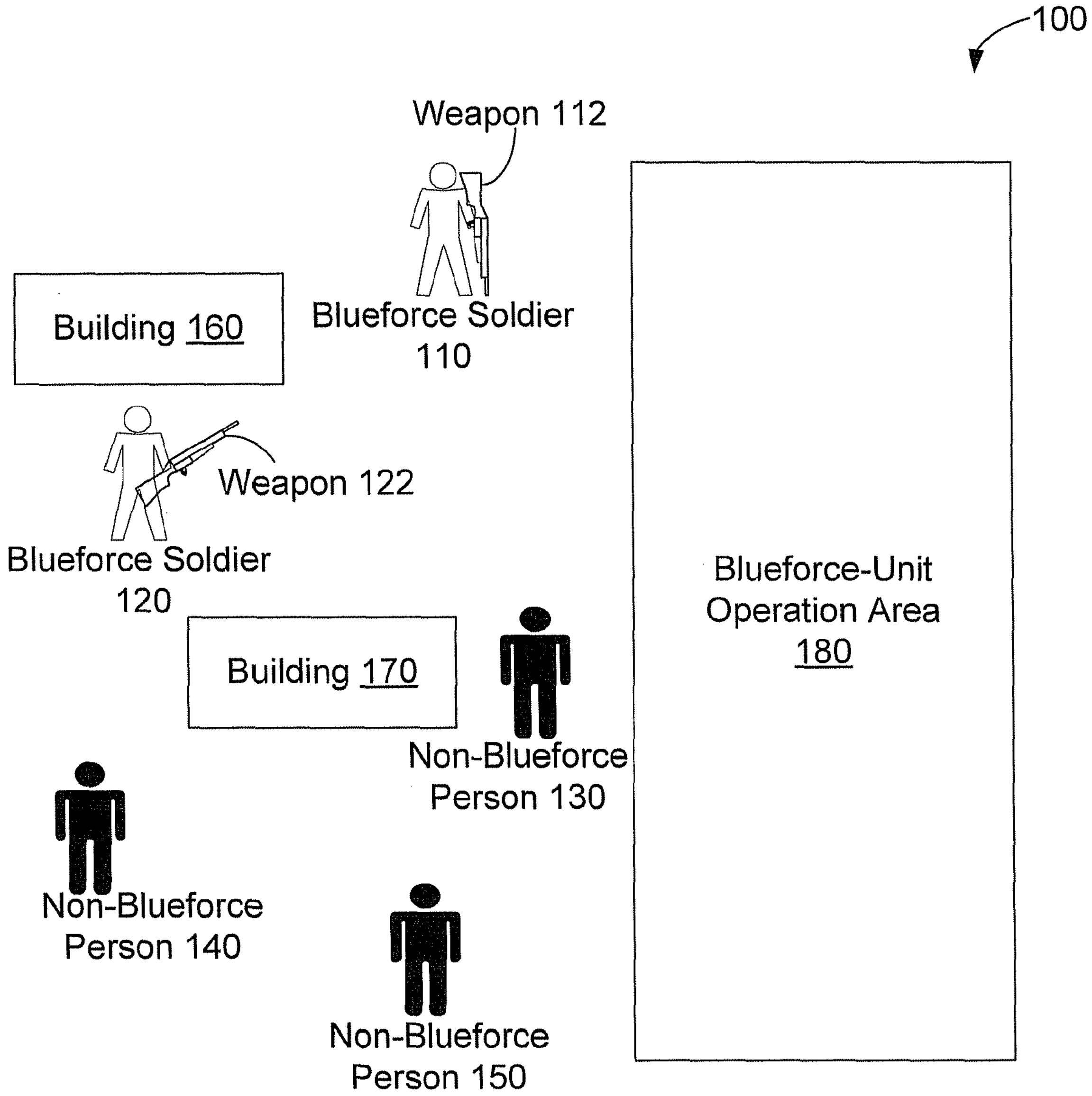
100
Weapon 112
Building 160
Blueforce Soldier 110
Weapon 122
Blueforce Soldier 120
Blueforce-Unit Operation Area 180
Building 170
Non-Blueforce Person 130
Non-Blueforce Person 140
Non-Blueforce Person 150

Figure 1

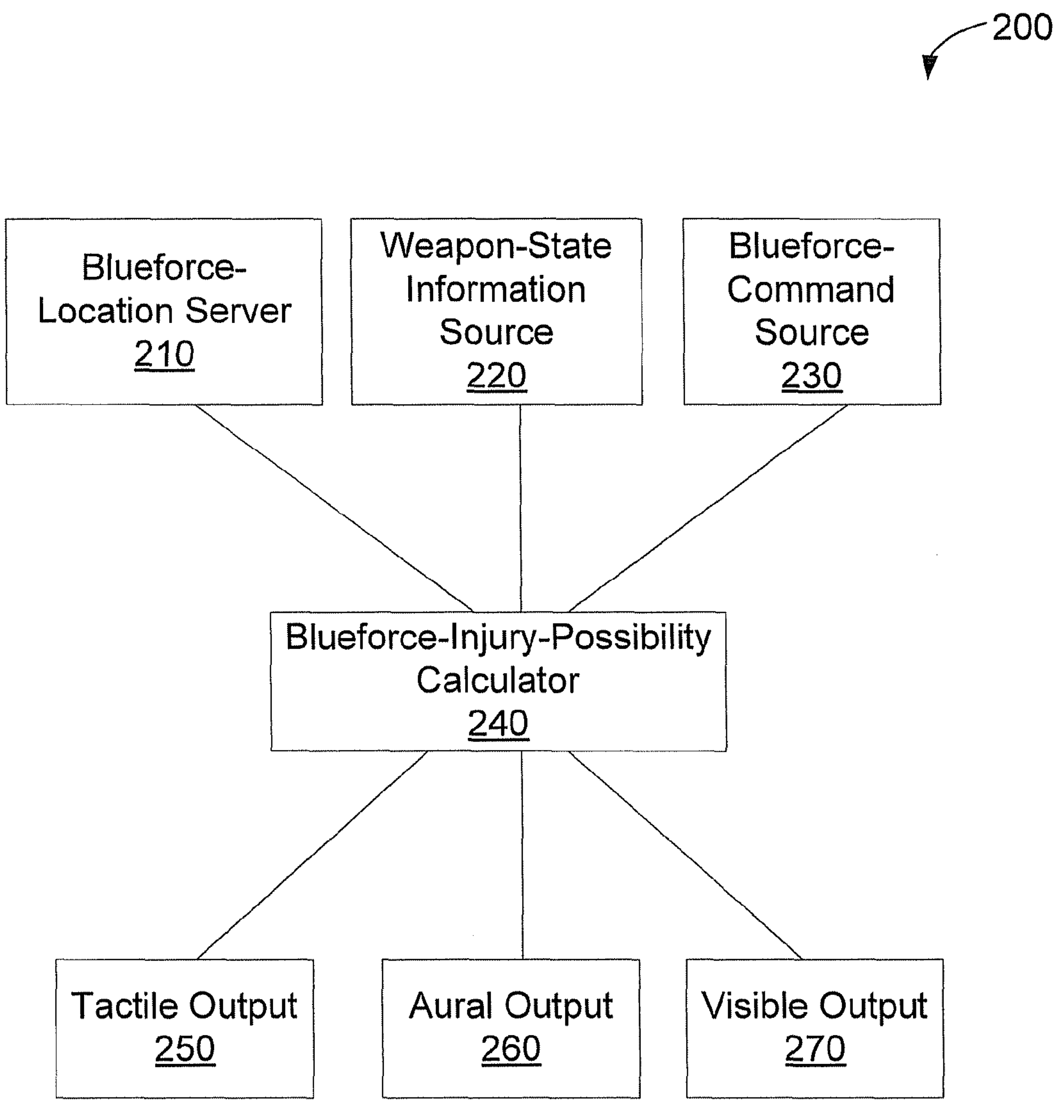
200
Blueforce-Location Server 210
Weapon-State Information Source 220
Blueforce-Command Source 230
Blueforce-Injury-Possibility Calculator 240
Tactile Output 250
Aural Output 260
Visible Output 270

Figure 2

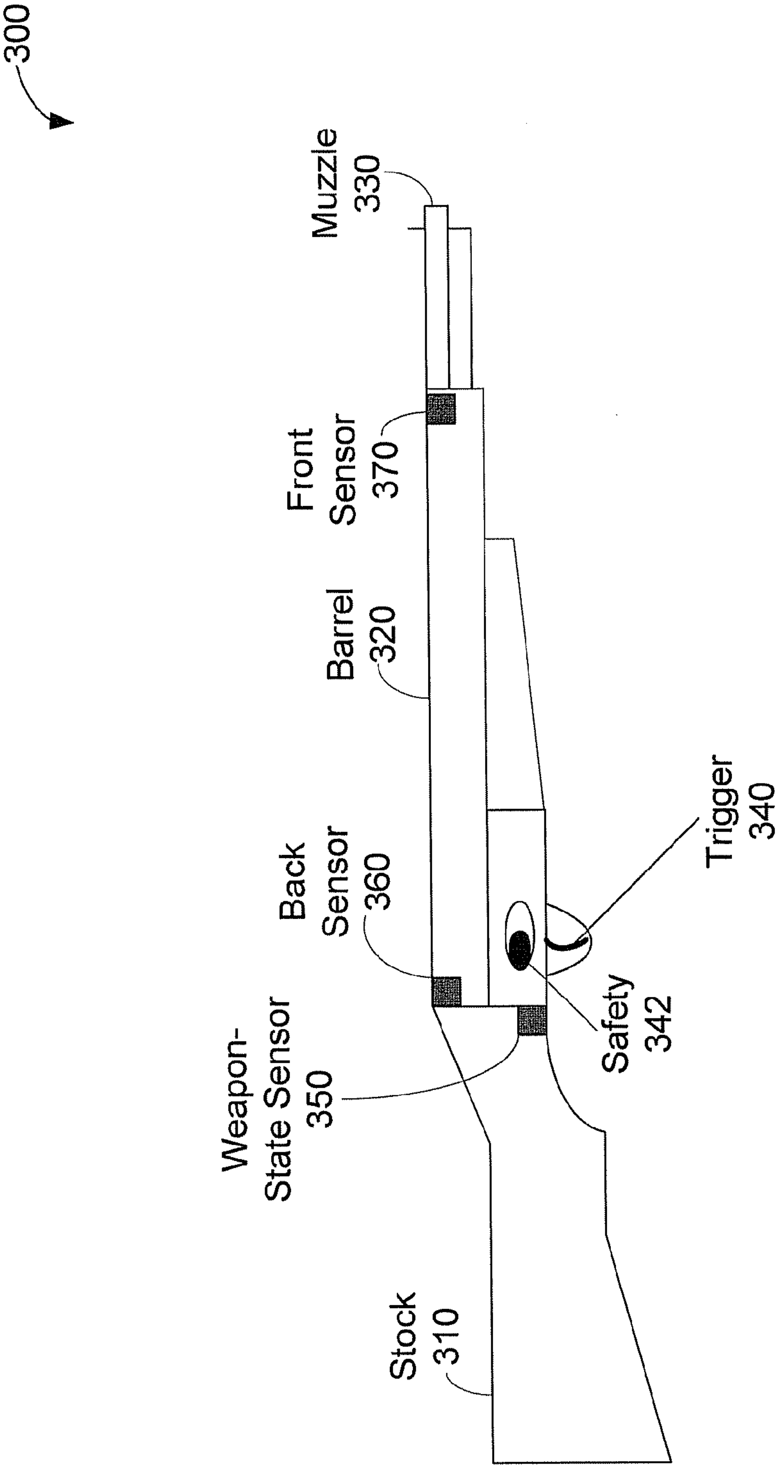
300
Muzzle
330
Front
Sensor
370
Barrel
320
Back
Sensor
360
Trigger
340
Safety
342
Weapon-
State Sensor
350
Stock
310

Figure 3

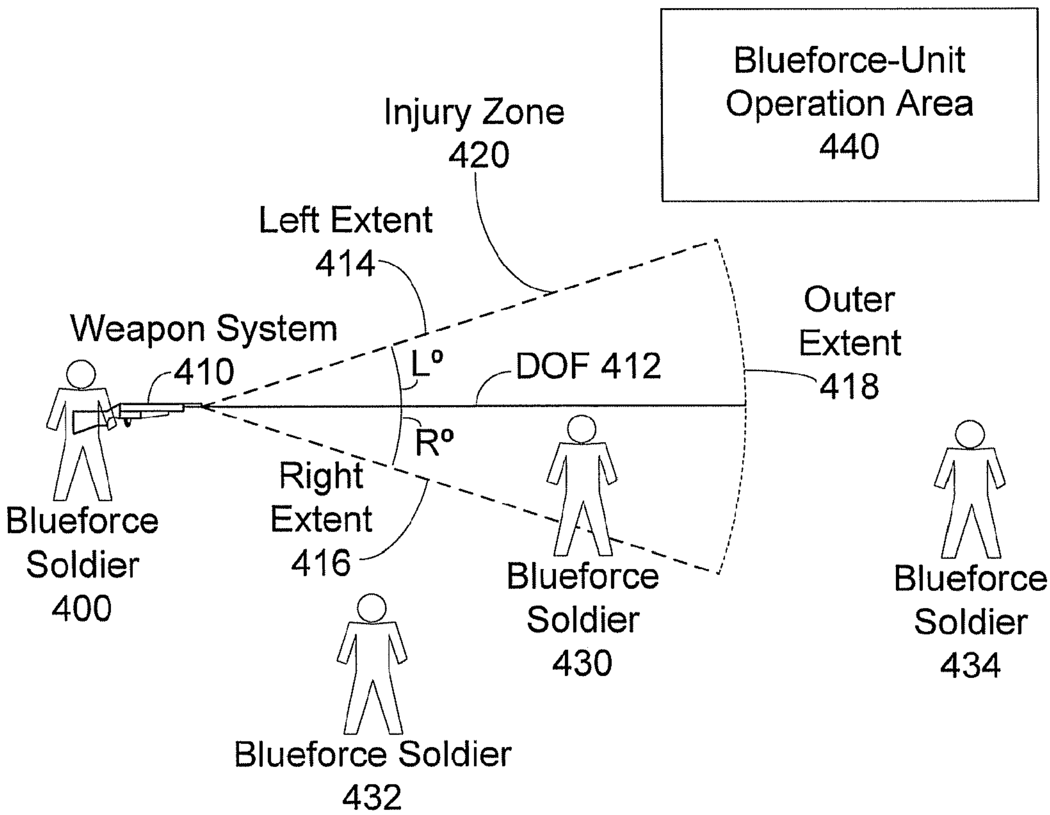

Figure 4A

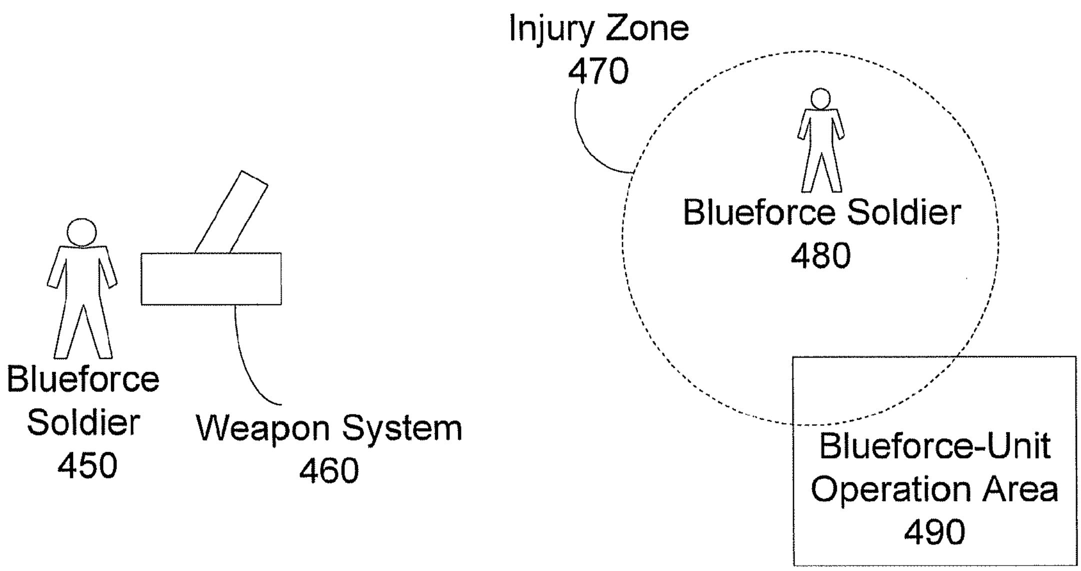

Figure 4B

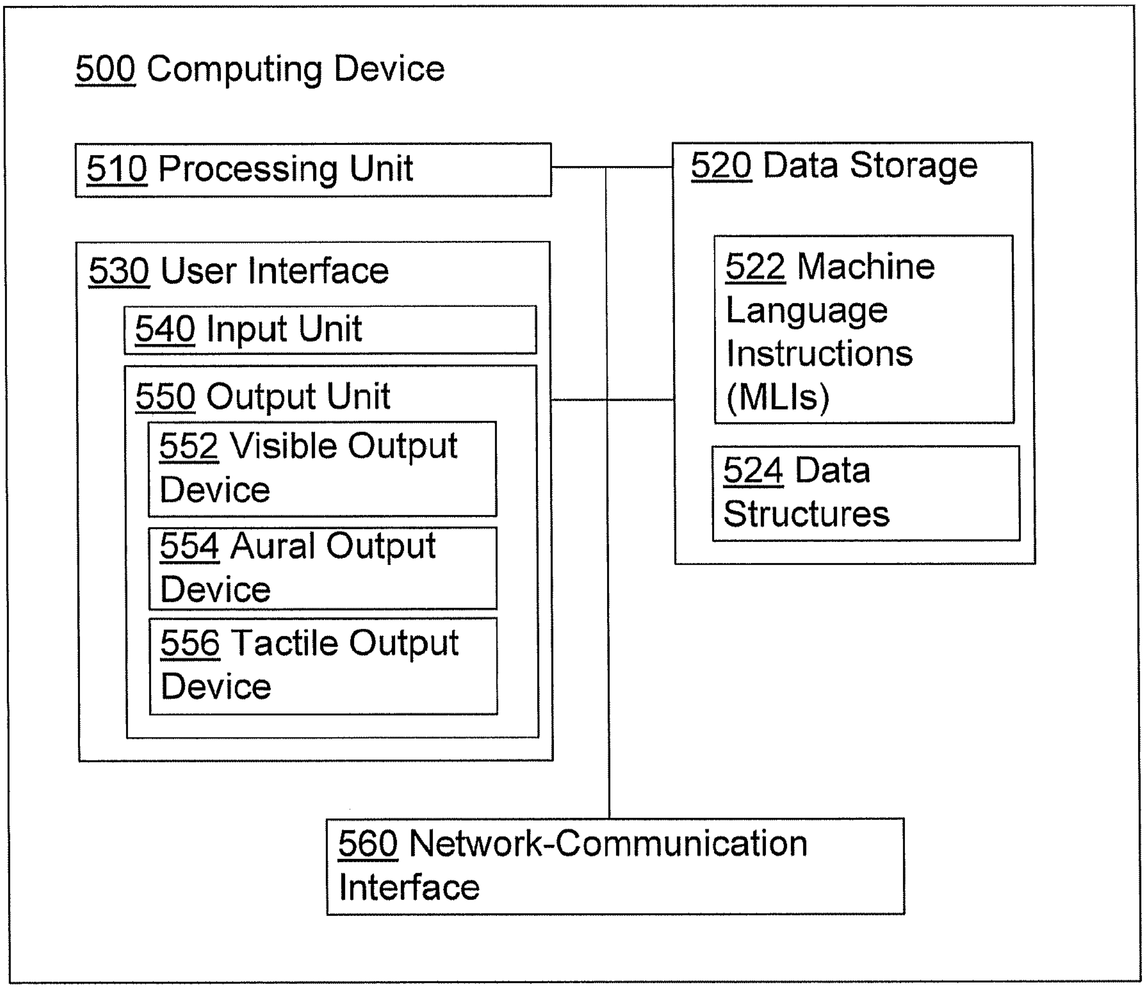
500 Computing Device
510 Processing Unit
520 Data Storage
530 User Interface
540 Input Unit
550 Output Unit
552 Visible Output Device
554 Aural Output Device
556 Tactile Output Device
522 Machine Language Instructions (MLIs)
524 Data Structures
560 Network-Communication Interface

Figure 5

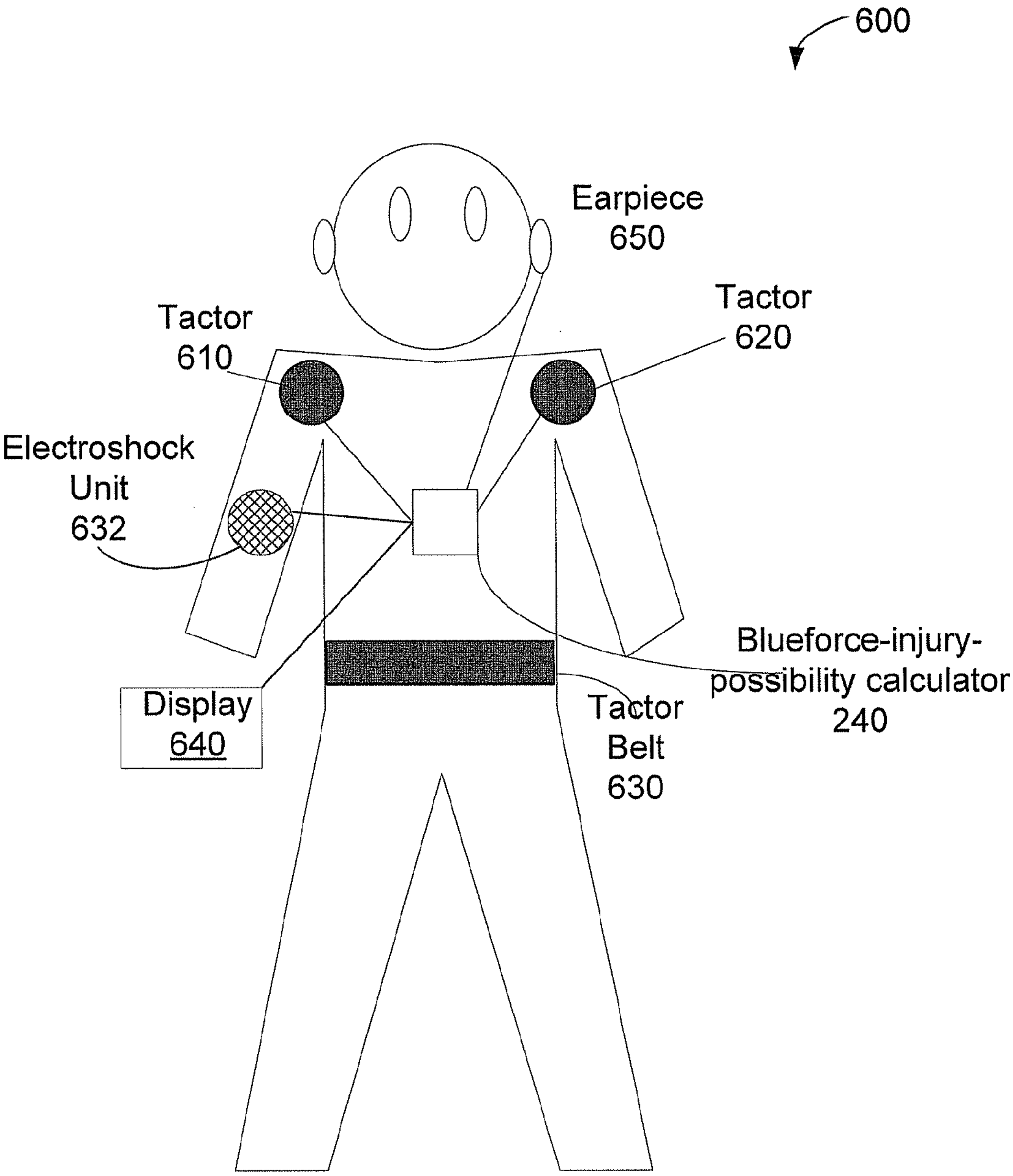
600
Earpiece
650
Tactor
610
Tactor
620
Electroshock
Unit
632
Blueforce-injury-
possibility calculator
240
Display
640
Tactor
Belt
630

Figure 6

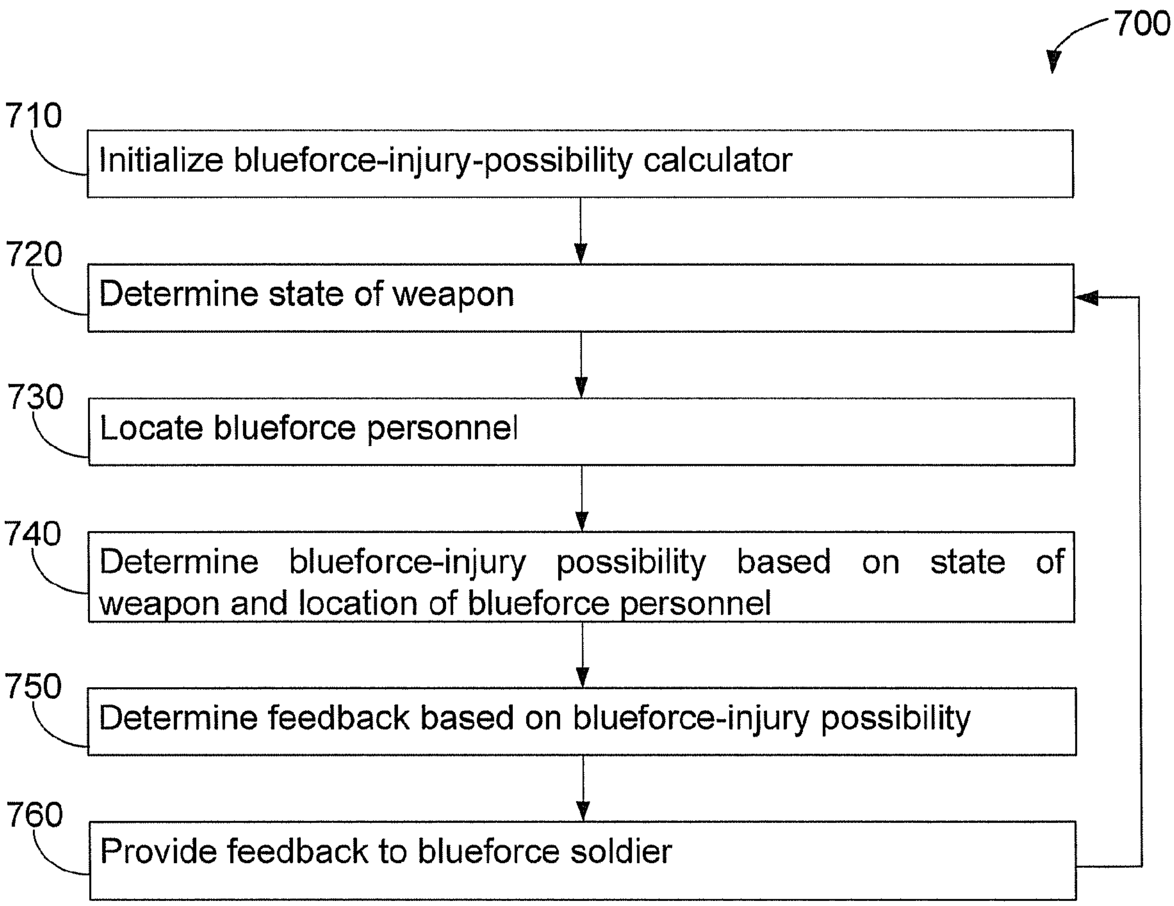
700
710
Initialize blueforce-injury-possibility calculator
720
Determine state of weapon
730
Locate blueforce personnel
740
Determine blueforce-injury possibility based on state of weapon and location of blueforce personnel
750
Determine feedback based on blueforce-injury possibility
760
Provide feedback to blueforce soldier

Figure 7

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **Roger W. Cholewiak ; Amy Collins.** Vibrotactile Pattern Discrimination and Communality at Several Body Sites. *Perception and Psychophysics,* 1995, vol. 57 (5), 724-37 **[0014]**
- **Aaron Bloomfield ; Norman I. Badler.** A Low Cost Tactor Suit for Vibrotactile Feedback. *University of Pennsylvania Department of Computer and Information Science,* 01 January 2003 **[0016]**