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(54) **IMPACT ABSORPTION APPARATUS FOR UNMANNED AERIAL VEHICLE**

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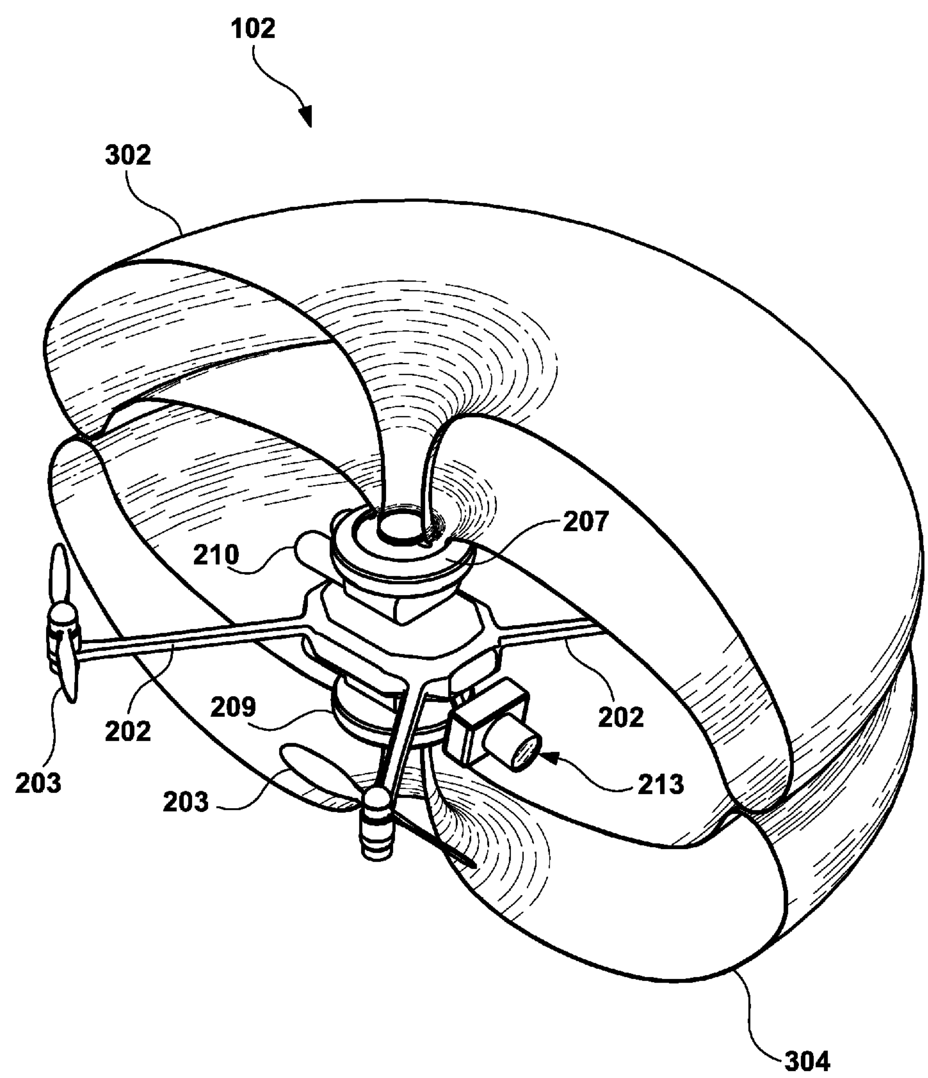
(57) **ABSTRACT**

An unmanned aerial vehicle apparatus comprises a frame. Further, the unmanned aerial vehicle apparatus comprises a propulsion mechanism coupled to the frame that propels the frame through the air. In addition, the unmanned aerial vehicle apparatus comprises a storage device that stores one or more airbags and is coupled to the frame. The unmanned aerial vehicle apparatus also comprises an inflation device coupled to the frame that receives an activation signal and inflates the one or more airbags based upon receipt of the activation signal to deploy the one or more airbags from the storage device prior to an impact of the frame with an object.



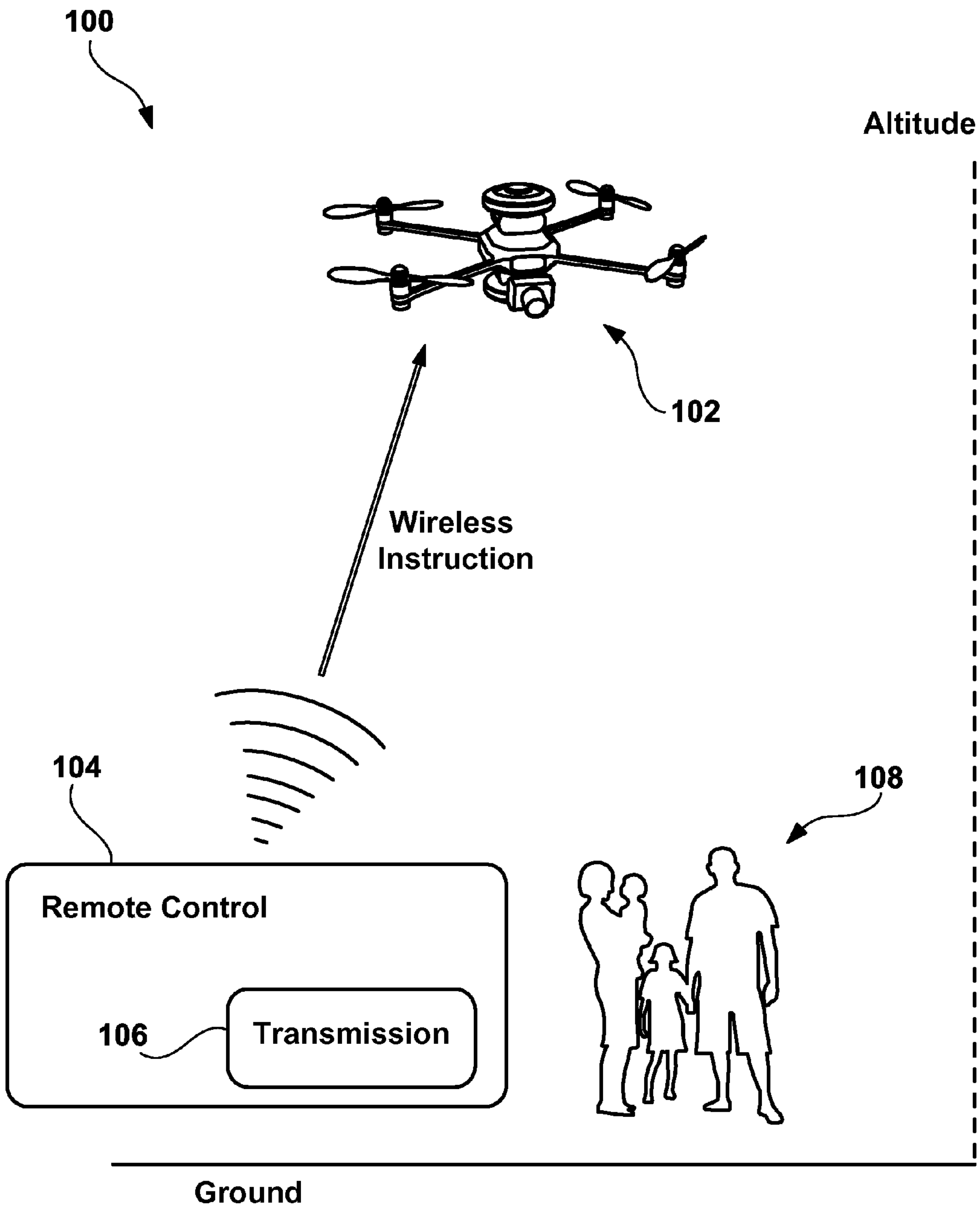

100
Altitude
102
Wireless
Instruction
104
108
Remote Control
106
Transmission
Ground

FIG. 1

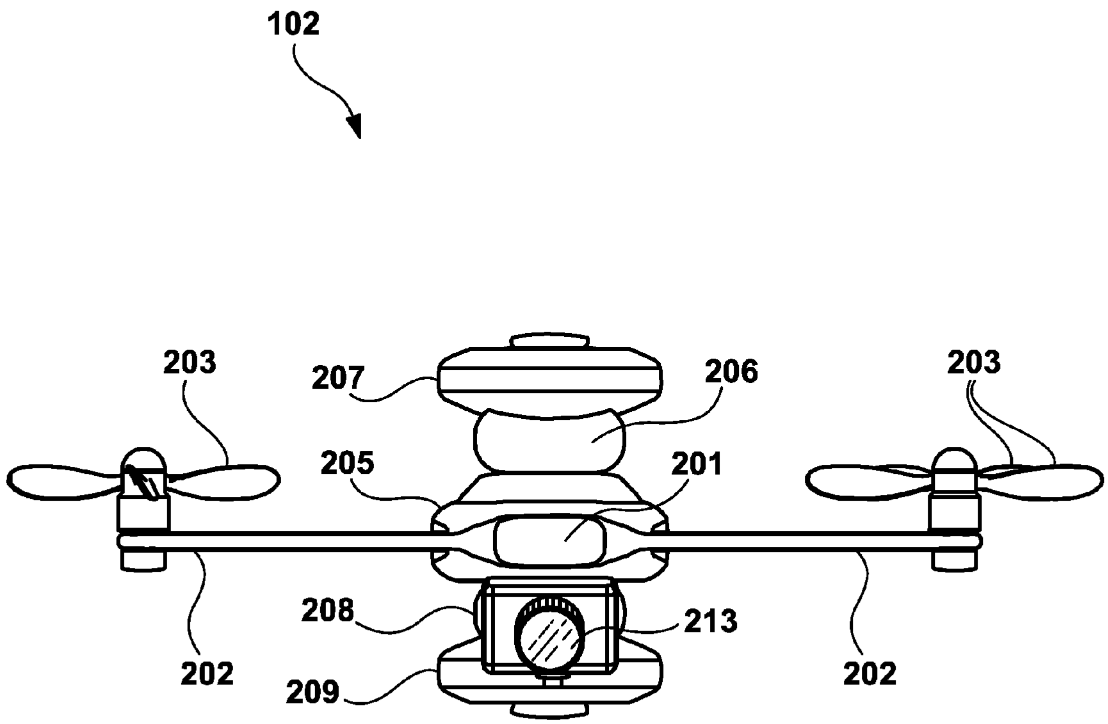


FIG. 2A

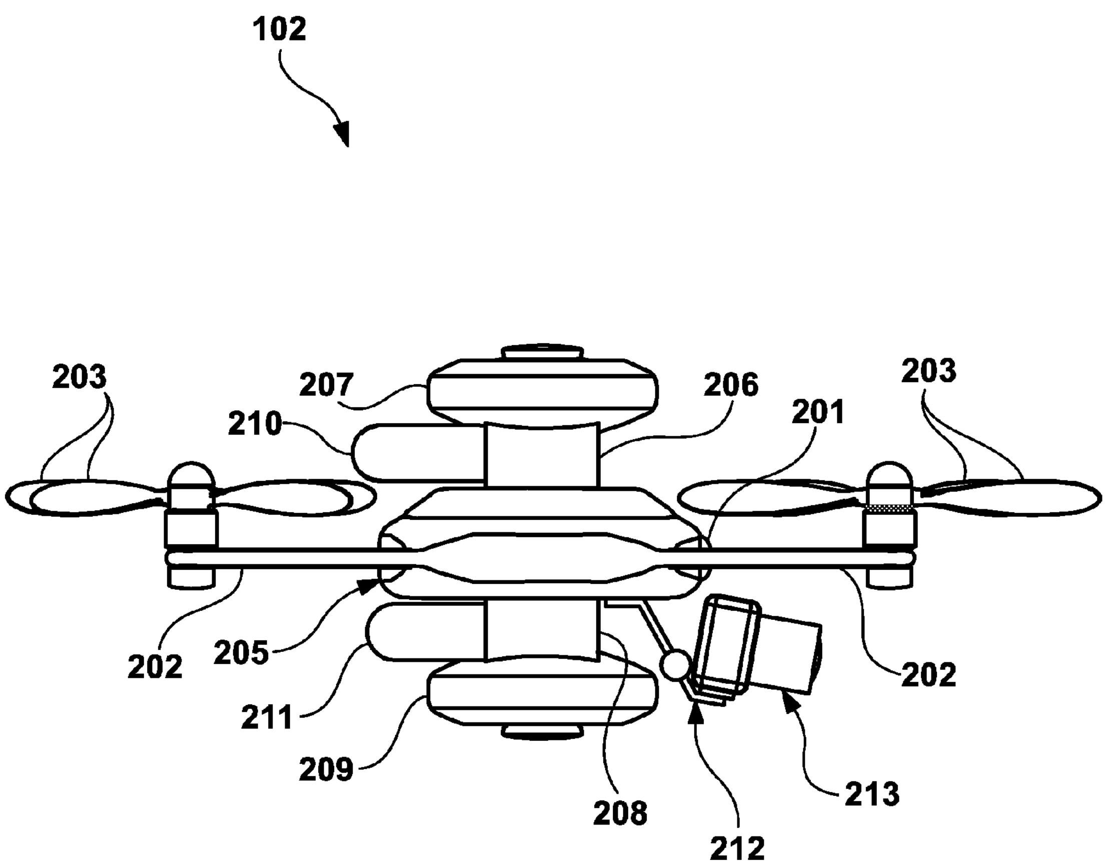


FIG. 2B

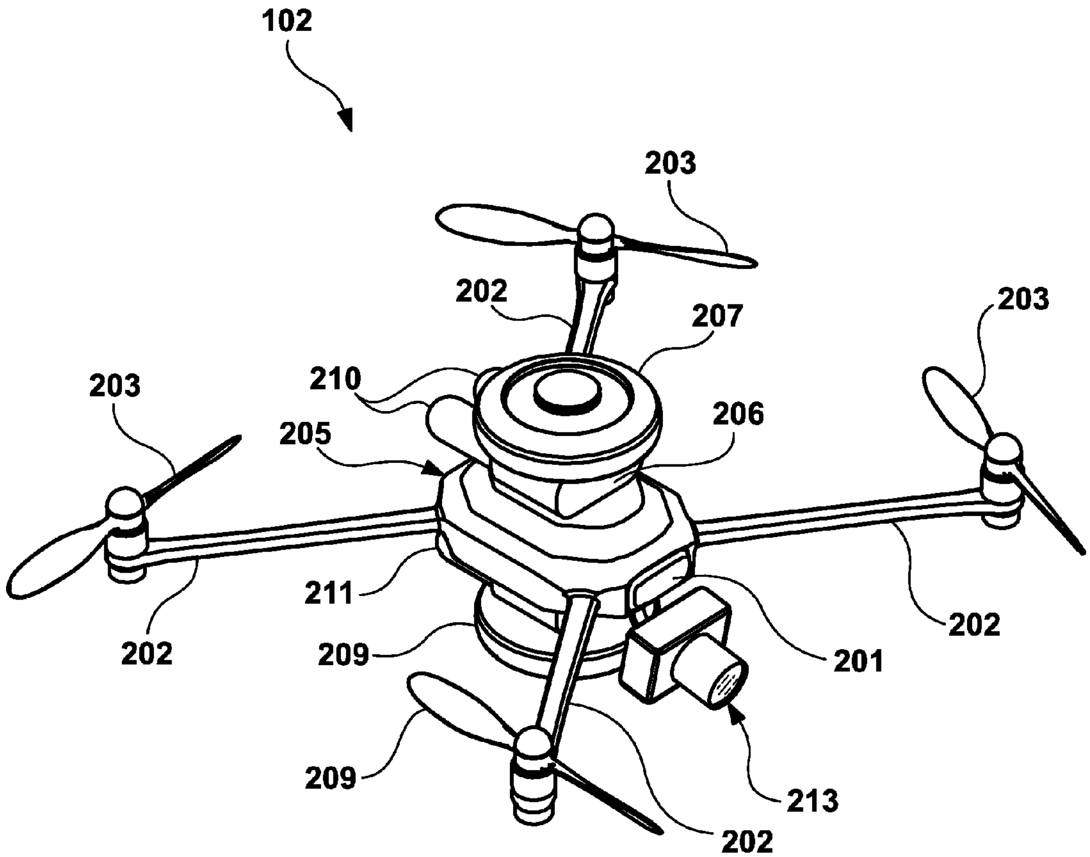

102
203
202
207
203
210
203
206
205
211
202
201
202
209
209
213
202

FIG. 2C

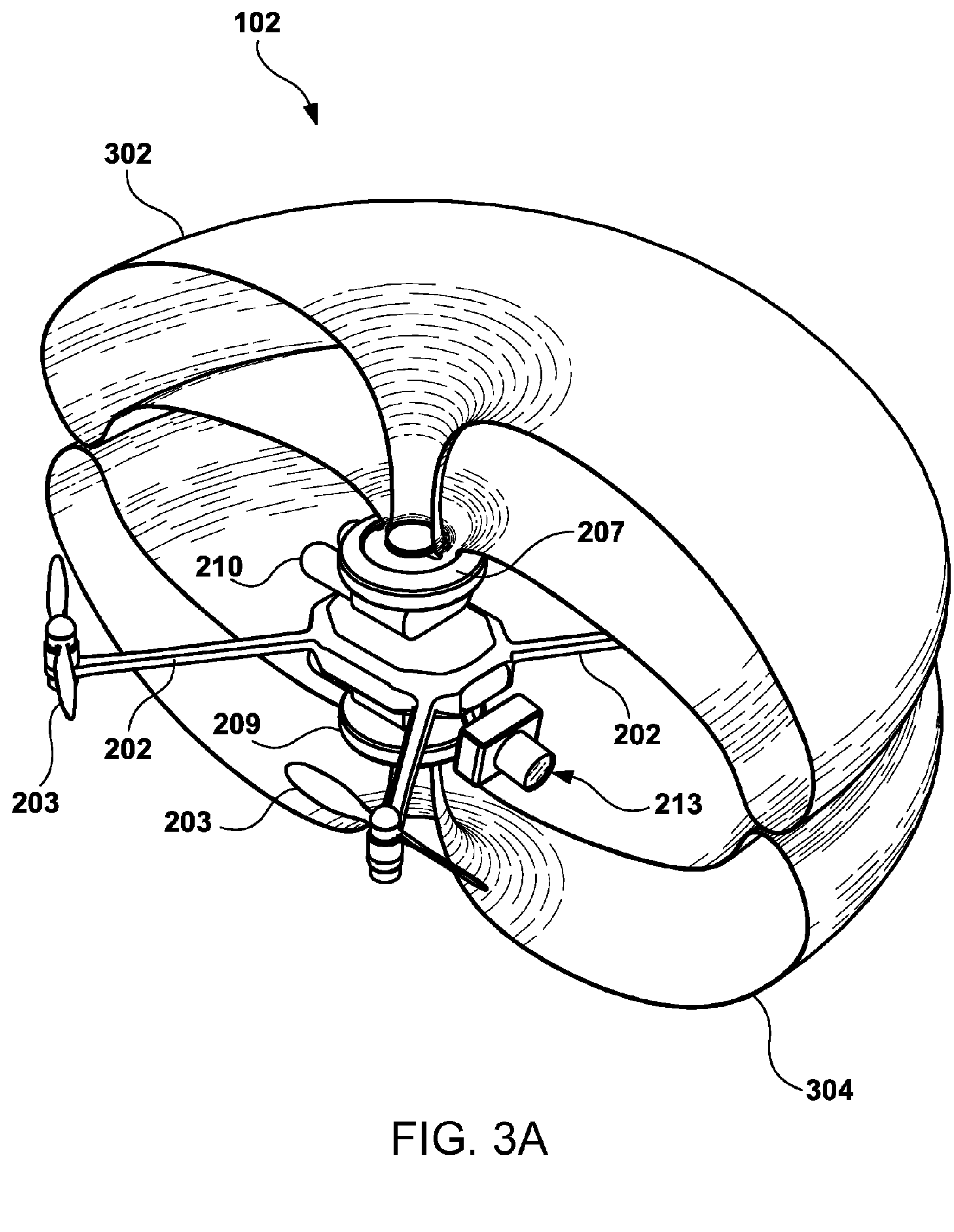


FIG. 3A

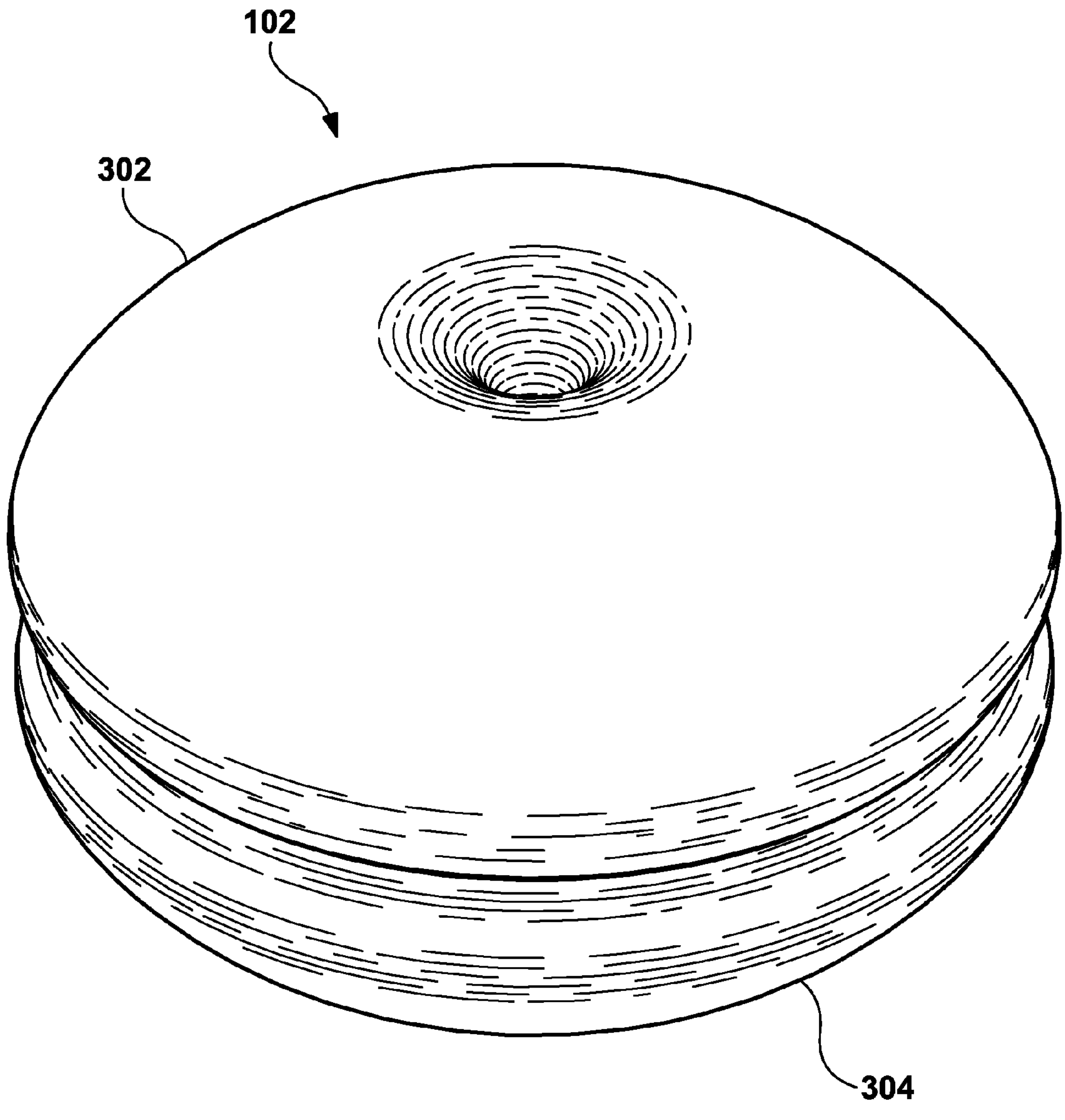


FIG. 3B

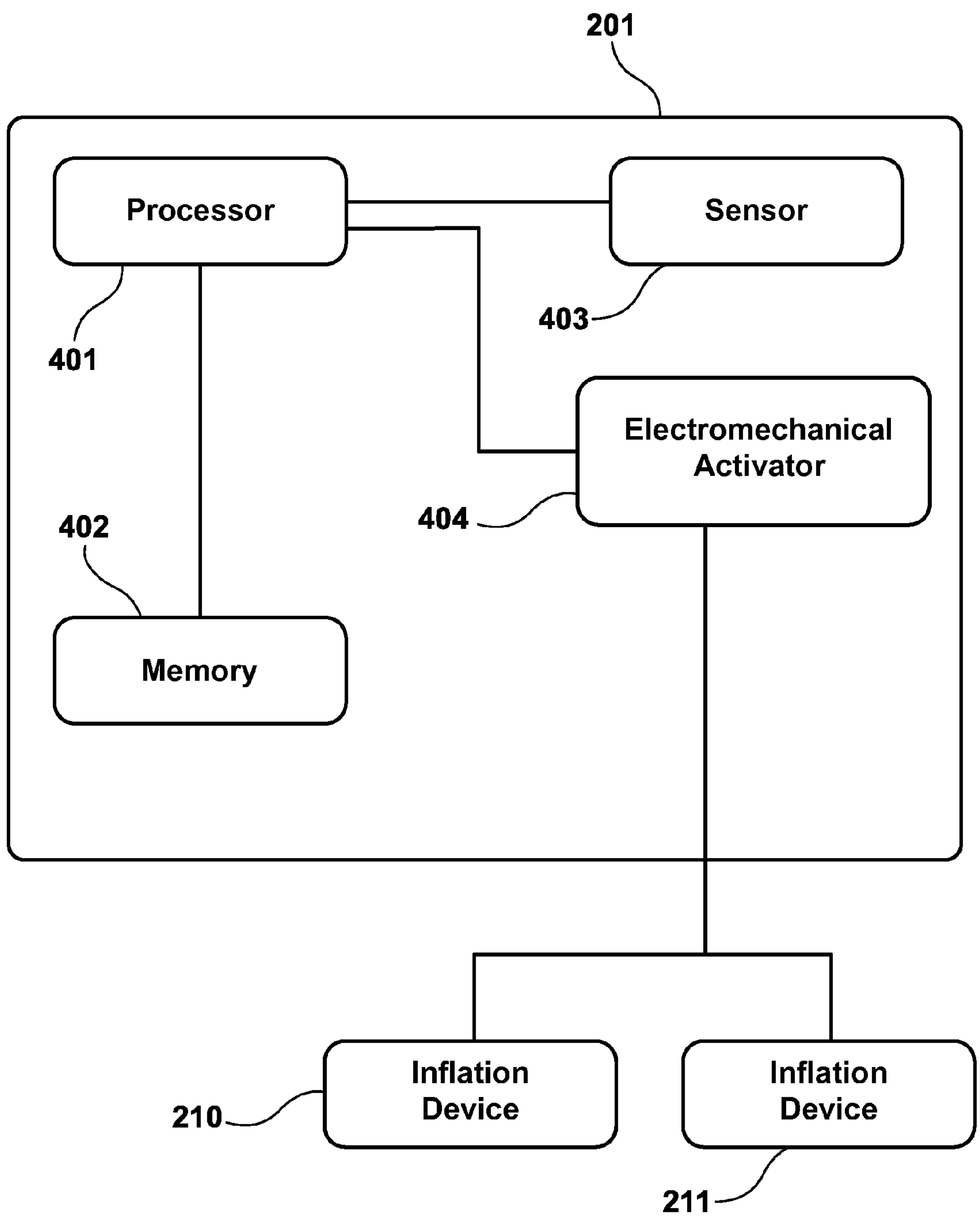

201
Processor
Sensor
401
403
Electromechanical Activator
404
402
Memory
Inflation Device
Inflation Device
210
211

FIG. 4

IMPACT ABSORPTION APPARATUS FOR UNMANNED AERIAL VEHICLE

BACKGROUND

[0001] 1. Field

[0002] This disclosure generally relates to the field of aerial vehicles. More particularly, the disclosure relates to safety mechanisms for aerial vehicles.

[0003] 2. General Background

[0004] Unmanned aerial vehicles ("UAVs") such as flying robots, drones, airplanes, helicopters, multicopters, e.g., flying robots that operate in a manner similar to helicopters with multiple propellers, balloons, etc. have become more commonplace in entertainment environments such as theme parks, film sets, sports environments, and news environments. A pilot can wirelessly navigate the UAV from a remote location. Alternatively, the UAV may have an auto-pilot feature so that it is operated and navigated by a computing device. A human is not present on the UAV during flight of the UAV. UAVs have been used for providing entertainment, aerial cinematography, gathering video, images, and/or audio, etc.

[0005] As UAVs increasingly fly over locations where people are present, safety for those people is an important goal. Equipment malfunction, aerial hazards, and aerial maneuvers are examples of events which may result in a loss of propulsion.

[0006] A previous solution was to attach a parachute to the UAV. The parachute could be ejected via a wireless instruction sent by a pilot or a computing device that operated the UAV or by on-board monitoring systems. A problem with using a parachute is that the parachute can get tangled with propulsion units of the UAV during or after ejection of the parachute. Typical UAVs, e.g. multicopters, are devices that are naturally unstable, hence malfunctions can result in a tumbling vehicle. For example, a multicopter can flip during ejection of the parachute. The parachute could then get entangled with the propulsion units of the multicopter during the flip and not eject properly or not provide much help in decelerating the multicopter if the parachute is ejected. Further, a parachute is often fabricated from a heavy material that significantly slows normal movement. Moreover, a parachute requires a fall distance to deploy and properly decelerate a vehicle. Therefore, a parachute is less effective at low altitude. As a result, a continuing need exists for robust UAV safety systems that do not impede normal operation and that perform well at low altitudes.

[0007] Another solution was the establishment of a geofence. The geofence allows the UAV to fly within a perimeter, e.g., a safe distance away from people or objects. Geofencing restricts the use and benefits of a UAV. Since a geofence is a control system rather than a physical barrier, the UAV can still fly through the geofence as a result of hardware or logic failure.

[0008] There is a continuous need to improve safety performance of UAVs.

SUMMARY

[0009] An unmanned aerial vehicle apparatus comprises a frame and a propulsion mechanism coupled to the frame that propels the frame through the air. A storage device stores one or more airbags and is coupled to the frame. An inflation device coupled to the frame receives an activation signal and in response inflates the one or more airbags prior to an impact of the frame with an object.

[0010] A method comprises propelling an unmanned aerial vehicle through the air. An activation signal is sent to an inflation device that inflates one or more airbags coupled to the aerial vehicle to deploy the one or more airbags from the storage device.

[0011] A system comprises a sensor that determines a condition of a component of an unmanned aerial vehicle. The unmanned aerial vehicle has one or more airbags and an inflation device. Further, the system comprises a processor that receives a signal from the sensor indicative of the condition of the component and sends an activation signal to the inflation device to deploy the one or more airbags from the storage device prior to an impact of the unmanned aerial vehicle with an object.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The above-mentioned features of the present disclosure will become more apparent with reference to the following description taken in conjunction with the accompanying drawings wherein like reference numerals denote like elements and in which:

[0013] FIG. **1** illustrates a UAV system.

[0014] FIGS. **2**A, **2**B, and **2**C illustrate a front view, a side view, and a perspective view of the components of the UAV apparatus illustrated in FIG. **1**.

[0015] FIGS. **3**A and **3**B illustrate an example of the UAV apparatus illustrated in FIGS. **2**A, **2**B, and **2**C partially deploying and fully deploying a first airbag and a second airbag.

[0016] FIG. **4** illustrates the internal electronic components of the electronic control device illustrated in FIGS. **2**A, **2**B, and **2**C.

DETAILED DESCRIPTION

[0017] A UAV comprising an impact absorption device is provided to improve safety in close proximity to a flying UAV. The impact absorption device is inflated by the UAV after detection of a condition that may lead to a ground impact, but prior to that impact. The inflated impact absorption device covers the hard, sharp, and spinning parts of the UAV, e.g., the propellers, the frame, etc. As a result, any impact of the UAV is with an inflated object rather than a hard or spinning UAV component. The impact absorption device is configured to prioritize reducing the effect of impact as opposed to preventing damage to the UAV.

[0018] As an example, the impact absorption device comprises one or more airbags that are each activated by one or more components of the UAV after the UAV detects a condition warranting activation. Such conditions include power failure, motor failure, guidance system failure, unexpected change in control source, navigation failure, air pressure change, change in acceleration or speed, mid-air collision with an obstacle and the like. For instance, a first airbag is positioned above the center of gravity of the UAV whereas a second airbag is positioned below the center of gravity of the UAV. Each airbag has dimensions such that both in total engulf the entire frame structure and propulsion mechanism, e.g., propellers, of the UAV. In contrast with previous approaches, e.g., the parachute configuration, that allowed different components of the UAV to be exposed after the safety mechanism was activated, the UAV uses the impact absorption device to engulf the hard, sharp and spinning components of the UAV to reduce the effect of impact.

[0019] The impact absorption device also helps slow the acceleration of the UAV during free fall. For instance, the UAV engulfed in two airbags will have significantly greater air resistance and so fall at a much slower velocity and acceleration than the UAV without two airbags. The resulting slower descent lowers the force of impact arising from contact with objects or the ground.

[0020] The impact absorption device is configured to lessen effects on flight performance in contrast with previous approaches, e.g., the parachute configuration, that used heavy materials that affected flight performance of a UAV. For example, each airbag can weigh less than one hundred grams. The airbag can be fabricated from an ultra lightweight film rather than a durable and puncture-proof material commonly used for parachutes. Therefore, the UAV can fly at similar speeds and perform similar maneuvers with the impact absorption device as if the UAV did not have the impact absorption device.

[0021] FIG. **1** illustrates a UAV system **100**. The UAV system **100** comprises a UAV **102**, e.g., a flying robot, drone, unmanned airplane, unmanned helicopter, unmanned multicopter, unmanned balloon, and a remote control **104** having a transmitter **106**. The UAV **102** flies autonomously or with remote human navigation above one or more people **108** and/or a plurality of objects (not shown). The remote control **104** is a wireless device that radiates Radio Frequency ("RF"), audio, or an optical signal to activate the impact absorption device. The signal can be generated by a human operator or autonomously via a computing device. The computing device can be an onboard device that executes instructions for the UAV. Alternatively, the computing device can be a remote land-based device that sends remote instructions to the UAV from an operator. The computing device can also be present onboard a neighboring or remotely situated distinct UAV. The instructions can go to a particular location in 3D space. If the UAV **102** flies autonomously, the UAV system **100** may operate without the remote control **104**.

[0022] FIGS. **2**A, **2**B, and **2**C illustrate a front view, a side view, and a perspective view of the components of the UAV apparatus **102** illustrated in FIG. **1**. The UAV apparatus **102** has a frame **205**, a plurality of connectors **206** and **208**, a plurality of storage devices **207** and **209**, and a plurality of inflation devices **210** and **211**. The connectors **206** and **208** can be platforms, chambers, arms, cages, or other types of mounting devices, that are used to connect the plurality of storage devices **207** and **209** to the frame **205**. The first storage device **207** is operably attached to the first inflation device **210**. Further, the second storage device **209** is operably attached to the second inflation device **211**.

[0023] The inflation devices **210** and **211** can be canisters of a compressed gas such as carbon dioxide. The inflation devices **210** and **211** are used to inflate impact absorption devices such as an airbag stored in the first storage device **207** and an airbag stored in the second storage device **209**. Although the inflation devices **210** and **211** are illustrated as being positioned within the connectors **206** and **208**, e.g., chambers, the inflation devices **210** and **211** can be situated on the top or sides of the storage devices **207** and **209**. Alternatively, the inflation devices **210** and **211** can be positioned on the connectors **206** and **208** in proximity to the first storage device **207** and the second storage device **209**. In addition, the first inflation devices **210** and **211** can take the form of a variety of different shapes and sizes. The inflation devices **210** and **211** can also be integrated within the first storage device **207** and the second storage device **209**.

[0024] The frame **205** also has the components of the UAV that are used to perform flight operation of the UAV. For instance, the frame **205** has a control device **201** that has the components for performing flight operation either autonomously or based upon an instruction received from the remote control **104**. The control device **201** also has sensors for detecting a UAV malfunction or other event in which the airbag should be deployed and one or more electromechanical actuators, e.g., valves, for activating the impact absorption device.

[0025] The frame **205** also has a plurality of arms **202** that are each operably connected to a propulsion mechanism **203**, e.g., a propeller mounted on a motor, where the motor is coupled to control device **201**. Control device **201** varies the speed of each of the propulsion devices **203** so as to control altitude and travel direction of UAV **102**. Other implementations may be operated with one propeller, e.g., a helicopter, or without any propellers, e.g., a balloon.

[0026] Further, a mounting device **212** may be used to mount various components to the frame **205**. For example, an image capture device **213** may be mounted to the frame **205**. The image capture device **213** may perform image capture during flight to allow a remotely positioned human pilot to navigate the UAV **102**.

[0027] FIGS. **3**A and **3**B illustrate an example of the UAV apparatus **102** illustrated in FIGS. **2**A, **2**B, and **2**C partially deploying and fully deploying a first airbag and a second airbag. The first airbag **302** is deployed from the first storage device **207** by the first inflation device **210** whereas the second airbag **304** is deployed from the second storage device **209** by the second inflation device **211**. The first airbag **302** has dimensions such that the first airbag **302** covers the propellers **203** attached to the frame **205**, the first storage device **207**, and a significant portion of the electronic control device **201**. Further, the second airbag **304** has dimensions such that the second airbag **304** covers the second storage device **209**, the mounting device **212**, the image capture device **213**, and a significant portion of the electronic control device **201**. The first airbag **302** and the second airbag **304** cover all of the propellers **203**, electronic components, and any other components that are part of or are attached to the frame **205** that may present hard, sharp or spinning components during free fall or impact. The airbags **302** and **304** together form a balloon-like structure. As the balloon-like structure is inflated it has a solid shape that absorbs large forces associated with rapid deceleration of UAV **102** upon impact. The inflation can be performed at various speeds, e.g., instantaneously, slowly, etc.

[0028] Although two inflation devices **210** and **211** are illustrated, a single inflation device may be used to inflate multiple airbags such as airbags **302** and **304**. For instance, a single inflation device, e.g., a valve, may be electromechanically operated by the electronic control device **201** to rotate to different storage devices **207** and **209** to inflate airbags **302** and **304**.

[0029] Further, a single airbag may be used if a portion of the UAV **102** has a soft payload. For instance, a UAV **102** that has a bottom portion with a soft material may only need a single airbag to cover an upper portion having sharp and other components that pose safety hazards. In addition, more than two airbags may be used to cover a UAV apparatus **102**. For example, a large UAV **102** may have many components that necessitate use of more than two airbags.

[0030] In one implementation, the airbags **302** and **304** are sealed. In other words, the airbags **302** and **304** do not release air upon impact unless there are punctures of the airbags **302** and **304**. In another implementation, the airbags **302** and **304** have vents that release air from the airbags **302** and **304** upon impact. The release of air upon impact helps further reduce forces resulting from impact.

[0031] FIG. **4** illustrates the internal components of the control device **201** illustrated in FIGS. **2**A, **2**B, and **2**C. The electronic control device **201** comprises a processor **401**, a memory **402**, a sensor **403**, and an activator **404**. The sensor(s) **403**, e.g., accelerometer, altimeter, gyroscope, etc., provides data, e.g., an activation signal, to the processor **401** so that the processor **401** can determine if the UAV apparatus **102** has malfunctioned or otherwise experienced an event that warrants deploying airbags.

[0032] A variety of different sensors **403** can be used to trigger an activation signal, which removes power from the propulsion devices, e.g., propellers **203** and/or activates the electromechanical activator **404**. The sensors **403** can detect the malfunction based on simplified logic criteria, i.e., sense a flip, a broken propeller, bad battery, electronic health failure, communication failure, or software failure.

[0033] As an example, the sensor **403** is an accelerometer that provides acceleration data to the processor **401** for storage in the memory **402**. Alternatively, the acceleration data can be stored in one or more registers of the processor **401**. The processor **401** then determines that the UAV apparatus **102** is accelerating faster than a predetermined acceleration. The processor **401** then determines that airbags **302** and **304** illustrated in FIGS. **3**A and **3**B should be deployed. The processor **401** sends an activation signal to the electromechanical activator **404** instructing the electromechanical activator **404** to activate inflation devices **210** and **211**. The inflation devices **210** and **211** then deploy airbags **302** and **304** from the first storage device **207** and the second storage device **209**.

[0034] As another example, the sensor **403** is an altimeter that determines altitude data for the UAV apparatus **102**. The processor **401** then determines that the UAV apparatus **102** is flying at an altitude that is less than a predetermined altitude. The processor **401** then determines that airbags **302** and **304** illustrated in FIGS. **3**A and **3**B should be deployed.

[0035] As yet another example, the sensor **403** is a gyroscope that determines pitch, roll, and/or yaw data. The gyroscope provides that data to the processor **401**, which can determine if the UAV is performing any unexpected rotations. As an example, the gyroscope sends the processor **401** data that indicates that the UAV had a pitch and roll each greater than seventy degrees. The processor **401** determines that such a rotation is a flip that was unexpected.

[0036] As another example, the sensor **403** is a current sensing sensor that determines if a motor (not shown) is consuming current. If the sensor **403** determines that the motor is not consuming any current or is consuming an abnormally high amount of current, the sensor **403** provides that data to the processor **401**, which may determine that a motor failure has occurred.

[0037] The sensor **403** may also be a component sensor, i.e., a sensor that determines that a component has malfunctioned. For instance, the sensor **403** may determine that a propeller **203** is not functioning properly. The sensor **403** sends the data to the processor **401** so that the processor **401** can determine if airbag deployment is necessary based upon whether or not the sensor data is within an acceptable threshold or range. The sensor **403** can also determine if a communication failure has occurred with a particular component.

[0038] The processor **404** is not necessary for operation of the sensor **403**. For example, a component attached to the sensor **403** can be configured to operate only if the sensor **403** provides a signal having a value in a certain range. For instance, the inflation devices **210** and **211** illustrated in FIGS. **2**A, **2**B, and **2**C may be operably attached to a sensor that detects if the motor is not consuming any current or is consuming an abnormally high amount of current. The inflation devices **210** and **211** are configured to be activated to inflate airbags if the sensor **403** does not provide any signal indicating current consumption or provides a signal of an abnormally high level of current.

1. A unmanned aerial vehicle comprising:
- a frame;
- a propulsion mechanism coupled to the frame that propels the frame through the air;
- one or more airbags coupled to the frame; and
- an inflation device coupled to the frame and to at least one of the one or more airbags, wherein the inflation device inflates the one or more airbags based upon receipt of an activation signal such that the one or more airbags engulf the frame and the propulsion mechanism.

2. The unmanned aerial vehicle of claim **1**, wherein the inflation device comprises a canister of carbon dioxide having an electromechanical activator.

3. The unmanned aerial vehicle of claim **1**, wherein the one or more airbags have inflated dimensions such that the frame and the propulsion mechanism are engulfed after inflation of the one or more airbags.

4. The unmanned aerial vehicle of claim **1**, further comprising a sensor that detects a component malfunction and sends the activation signal to the inflation device upon the detection of the component malfunction.

5. The unmanned aerial vehicle of claim **1**, further comprising an altimeter producing an altitude signal; and
- a processor coupled to receive the altitude signal, the processor executing code configured to determine whether the frame experiences a change in altitude, the processor sending the activation signal to the inflation device upon the processor determining that the frame is flying outside of an altitude range.

6. The unmanned aerial vehicle of claim **1**, further comprising an accelerometer producing an acceleration signal or loss of signal; and
- a processor coupled to receive the acceleration signal, the processor executing code configured to determine whether the frame experiences a change in acceleration , the processor sending the activation signal to the inflation device upon the processor determining that the frame is accelerating at an acceleration in excess of a predetermined acceleration.

7. The unmanned aerial vehicle apparatus of claim **1**, further comprising a receiver that receives an instruction from a pilot remotely positioned from the unmanned aerial vehicle and sends the activation signal to the inflation device based upon the instruction.

8. The unmanned aerial vehicle of claim **1**, wherein the one or more airbags are positioned above and below a center of gravity of the frame along the vertical centerline of the frame.

9. The unmanned aerial vehicle of claim **1**, wherein the one or more airbags are sealed that prevent air from the one or more airbags to be dissipated upon the impact.

10. The unmanned aerial vehicle of claim **1**, wherein the one or more airbags have one or more vents that allow air from the one or more airbags to be dissipated upon the impact.

11. A method comprising:

propelling an unmanned aerial vehicle through the air, the unmanned aerial vehicle having one or more airbags; and

sending an activation signal to an inflation device that inflates the one or more airbags such that the one or more airbags engulf the frame and the propulsion mechanism based upon receipt of the activation signal to deploy the one or more airbags from the storage device prior to an impact of the unmanned aerial vehicle with an object.

12. The method of claim **11**, further comprising detecting a condition of a component and sending the activation signal to the inflation device upon the detection of the condition of the component.

13. The method of claim **11**, further comprising:

determining that the unmanned aerial vehicle experiences a change in altitude; and

sending the activation signal to the inflation device upon determining that the unmanned aerial vehicle is flying beneath a predetermined altitude.

14. The method of claim **11**, further comprising:

determining that the frame experiences a change in acceleration; and

sending the activation signal to the inflation device upon determining that the unmanned aerial vehicle is accelerating at an acceleration in excess of a predetermined acceleration.

15. The method of claim **11**, further comprising:

receiving an instruction from a pilot remotely positioned from the unmanned aerial vehicle apparatus; and

sending the activation signal to the inflation device based upon the instruction.

16. A system comprising:

a sensor that determines a condition of a component of an unmanned aerial vehicle, the unmanned aerial vehicle having a storage device that stores one or more airbags and an inflation device; and

a processor that receives a malfunction signal from the sensor indicative of the condition of the component and sends an activation signal to the inflation device to deploy the one or more airbags from the storage device such that the one or more airbags engulf the frame and the propulsion mechanism prior to an impact of the unmanned aerial vehicle with an object.

17. The system of claim **16**, wherein the sensor is an altimeter.

18. The system of claim **16**, wherein the sensor is an accelerometer.

19. The system of claim **16**, wherein the inflation device is a canister of carbon dioxide having an electromechanical activator.

20. The system of claim **16**, wherein the one or more airbags have dimensions such that the frame and the propulsion mechanism are engulfed after inflation of the one or more airbags.

* * * * *