US007149611B2

(12) **United States Patent**
Beck et al.

(10) **Patent No.: US 7,149,611 B2**
(45) **Date of Patent: Dec. 12, 2006**

(54) **VIRTUAL SENSOR MAST**

(75) Inventors: **Michael S. Beck**, Colleyville, TX (US); **Wendell H. Chun**, Littleton, CO (US); **Jon T. Stinchcomb**, Arlington, TX (US)

(73) Assignee: **Lockheed Martin Corporation**, Bethesda, MD (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 161 days.

(21) Appl. No.: **10/639,267**

(22) Filed: **Aug. 12, 2003**

(65) **Prior Publication Data**

US 2004/0167682 A1 Aug. 26, 2004

Related U.S. Application Data

(60) Provisional application No. 60/449,271, filed on Feb. 21, 2003.

(51) **Int. Cl.**
G01M 17/00 (2006.01)

(52) **U.S. Cl.** **701/29**; 701/11; 701/15; 244/3.15; 244/171

(58) **Field of Classification Search** 701/23, 701/3, 11, 15–16, 29; 244/3.1, 3.11, 3.12, 244/3.15, 3.2, 12.2–12.3, 17.11, 17.13, 17.14, 244/17.15, 32, 171
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,880,103	A *	4/1975	Talkington	405/185
4,757,962	A *	7/1988	Grant	244/12.3
4,860,968	A *	8/1989	Pinson	244/3.12
5,170,963	A *	12/1992	Beck, Jr.	244/12.2
5,186,414	A *	2/1993	Holzschuh et al.	244/3.12
5,310,134	A *	5/1994	Hsu et al.	244/3.12
6,270,038	B1 *	8/2001	Cycon et al.	244/12.3
6,397,063	B1 *	5/2002	Sessions et al.	455/425
6,813,218	B1 *	11/2004	Antonelli et al.	367/3
2002/0109045	A1 *	8/2002	Beach et al.	244/33

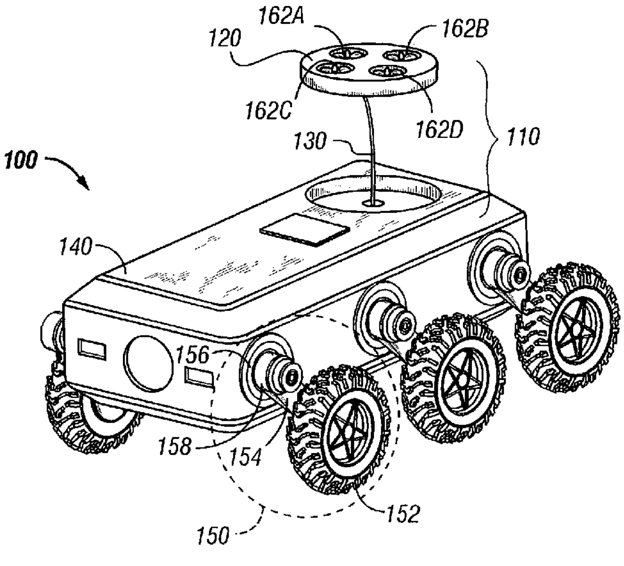
* cited by examiner

Primary Examiner—Gertrude A. Jeanglaude
(74) *Attorney, Agent, or Firm*—Williams, Morgan & Amerson

(57) **ABSTRACT**

A virtual sensor mast for a ground vehicle and a method for operating a ground vehicle using a virtual sensor mast are disclosed. The virtual sensor mast includes an unmanned airborne vehicle capable of lifting itself from the ground vehicle upon deployment therefrom; a sensor suite mounted to the unmanned airborne vehicle; and a tether between the unmanned airborne vehicle and the ground vehicle over which the sensor suite is capable of communicating sensed data upon deployment. The method includes elevating a tethered unmanned airborne vehicle from the ground vehicle to a predetermined height; sensing environmental conditions surrounding the ground vehicle; and terminating the deployment.

48 Claims, 9 Drawing Sheets



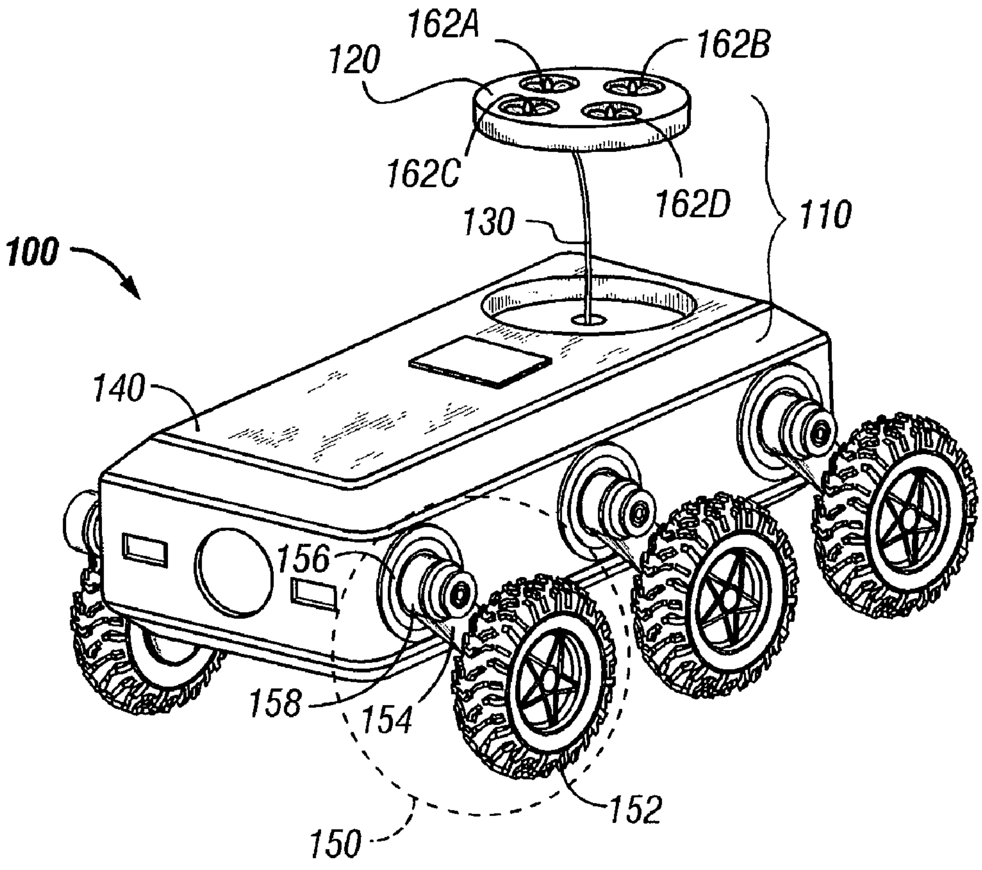

162A
162B
120
162C
162D
130
110
100
140
156
158
154
152
150

FIG. 1

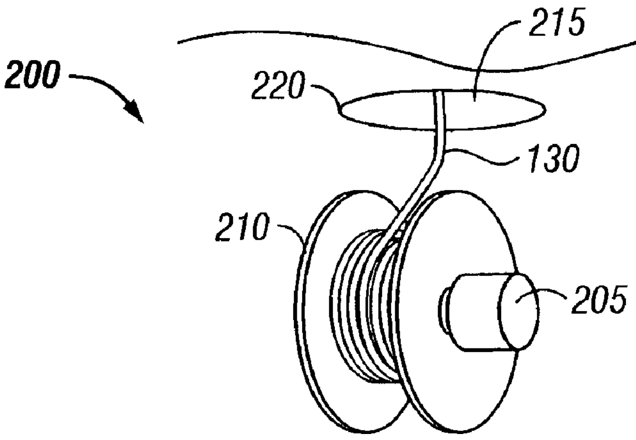

215
200
220
130
210
205

FIG. 2

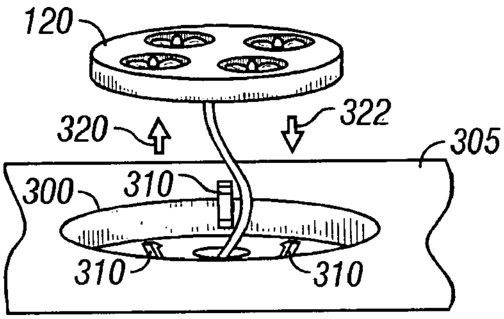


FIG. 3A

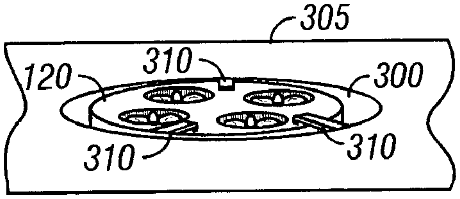


FIG. 3B

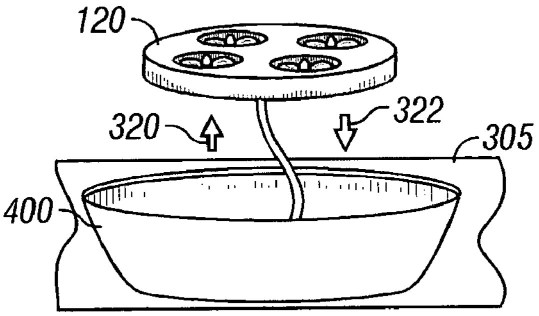


FIG. 4A

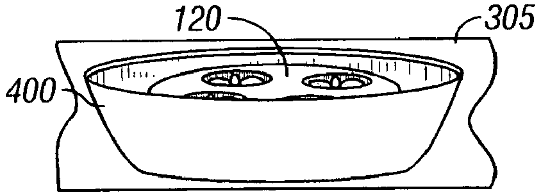


FIG. 4B

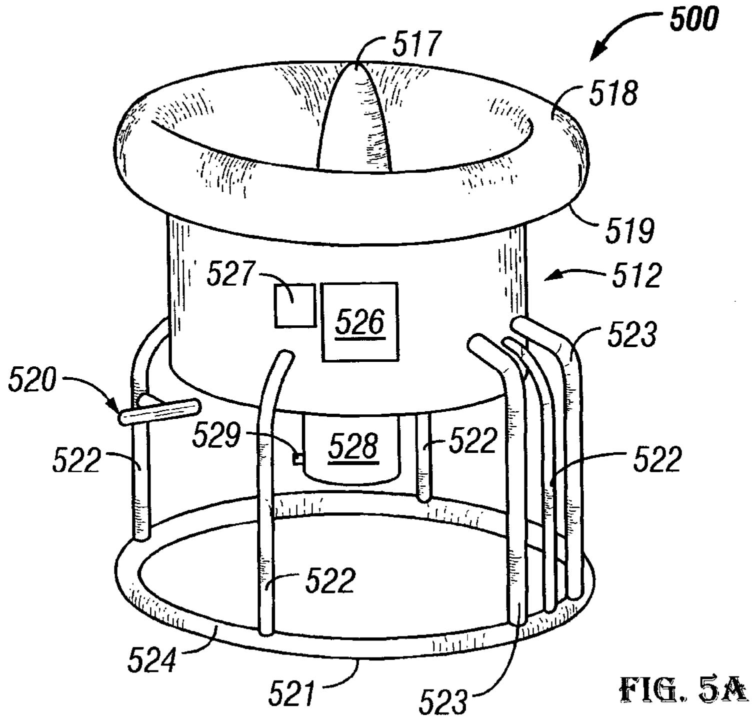

500
517
518
519
512
527
526
523
520
529
528
522
522
522
522
522
524
521
523

FIG. 5A

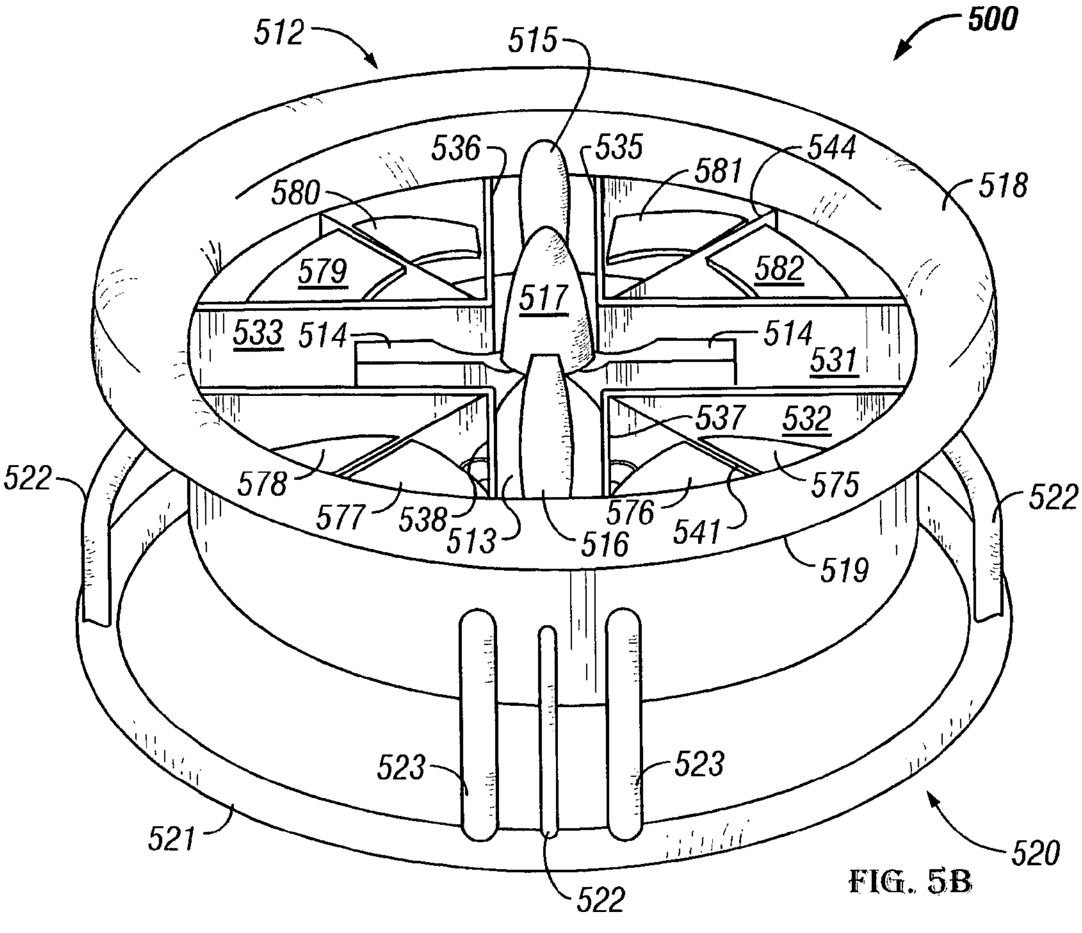

512
500
515
536
535
544
518
580
581
579
582
517
533
514
514
531
537
532
578
575
577
538
513
516
576
541
519
522
522
523
523
521
522
520

FIG. 5B

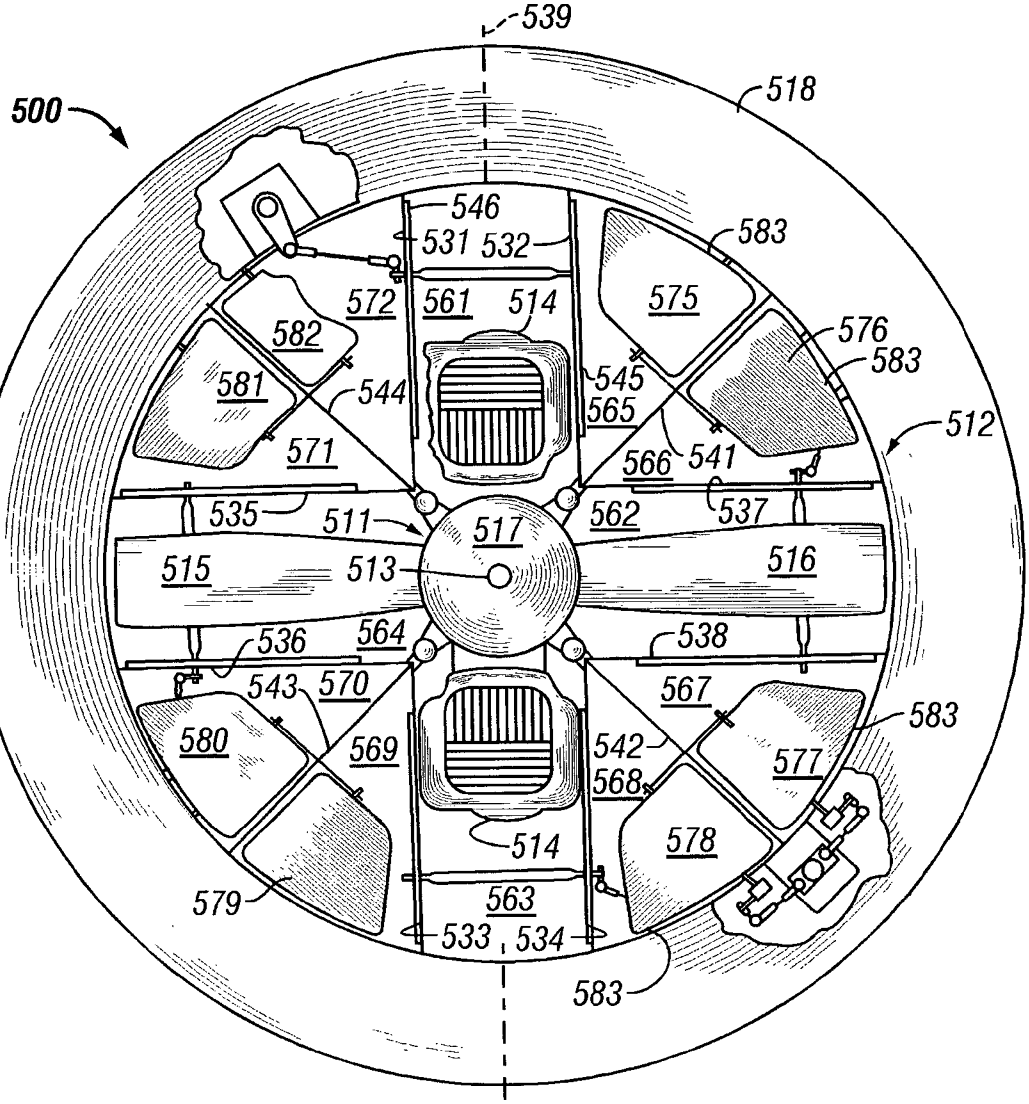

539
500
518
546
531
532
583
572
561
514
575
576
582
583
581
544
545
565
512
571
566
541
535
511
517
562
537
515
513
516
536
564
538
543
570
567
583
580
569
542
577
568
514
578
563
579
533
534
583

FIG. 5C

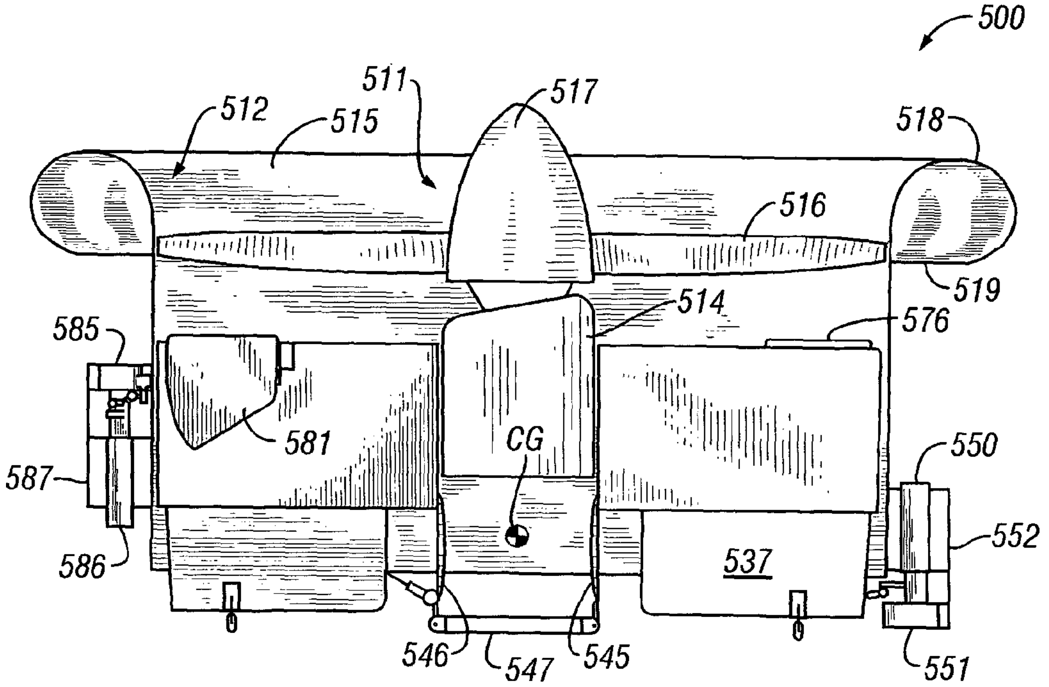

500
511
512
515
517
518
516
519
514
576
585
581
587
586
CG
550
552
537
546
547
545
551

FIG. 5D

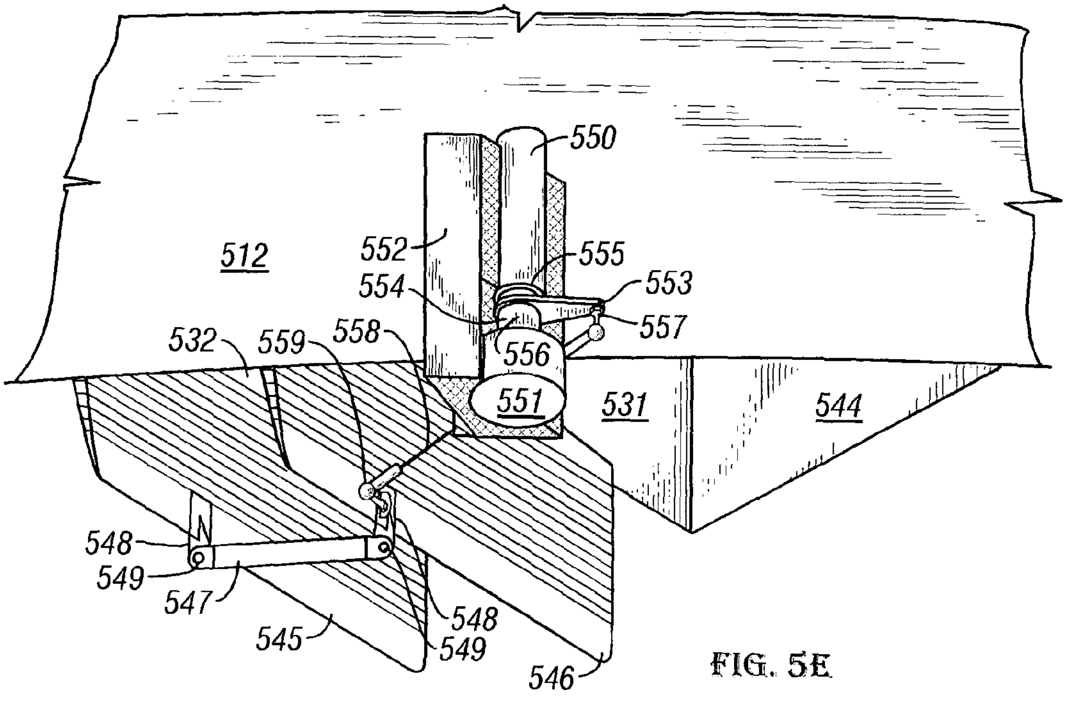

550
512
552
555
553
554
557
532
559
558
556
551
531
544
548
549
547
548
545
549
546

FIG. 5E

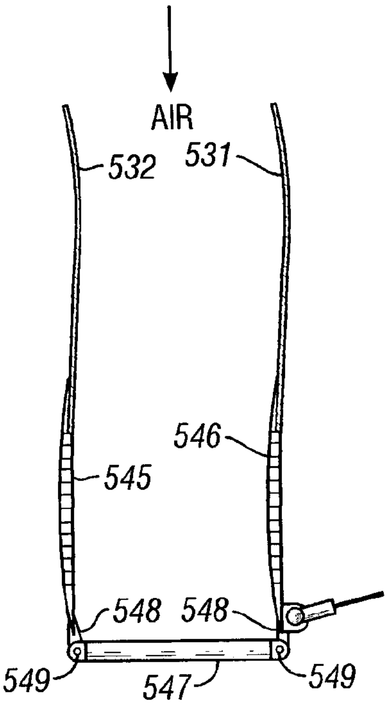


FIG. 5F

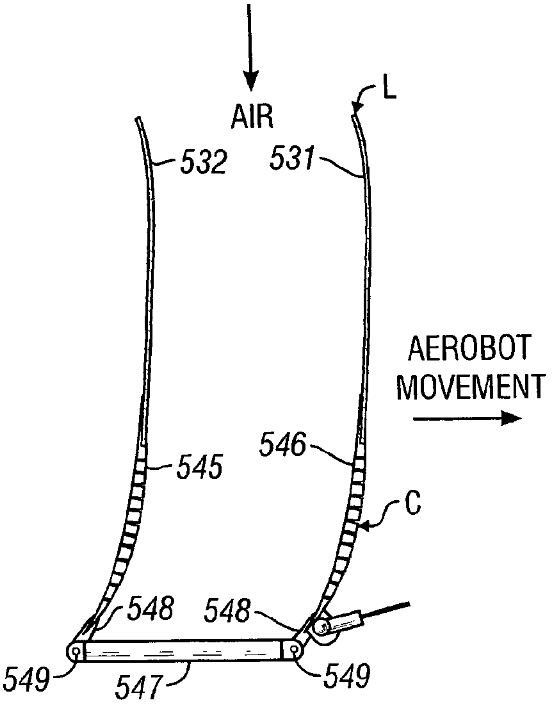


FIG. 5G

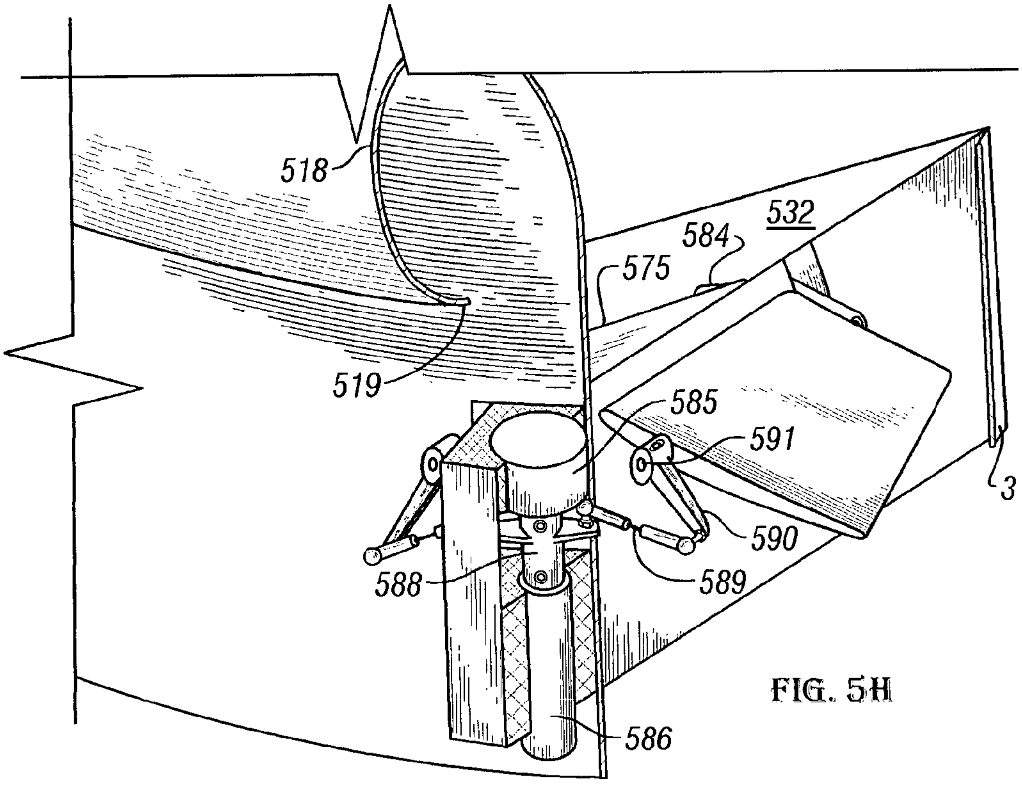


FIG. 5H

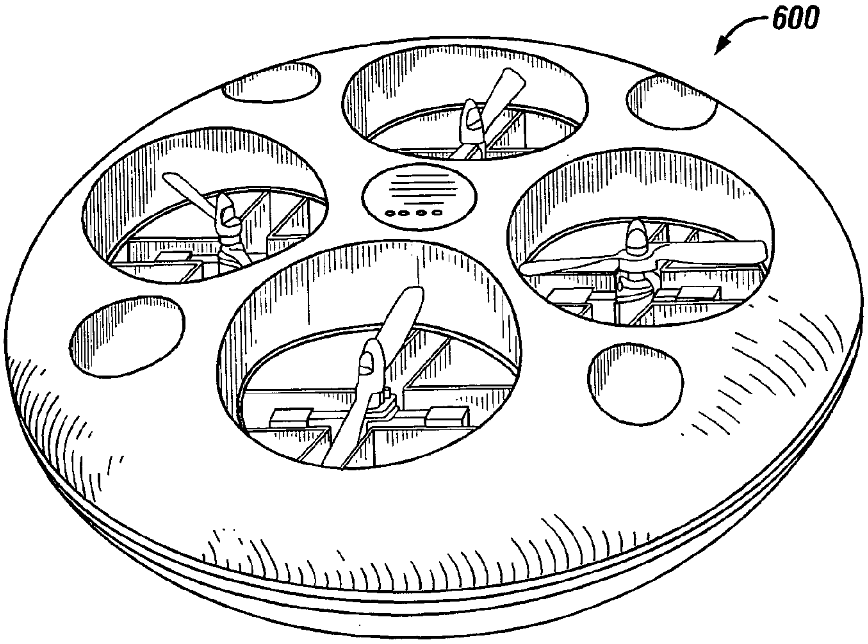

600

FIG. 6

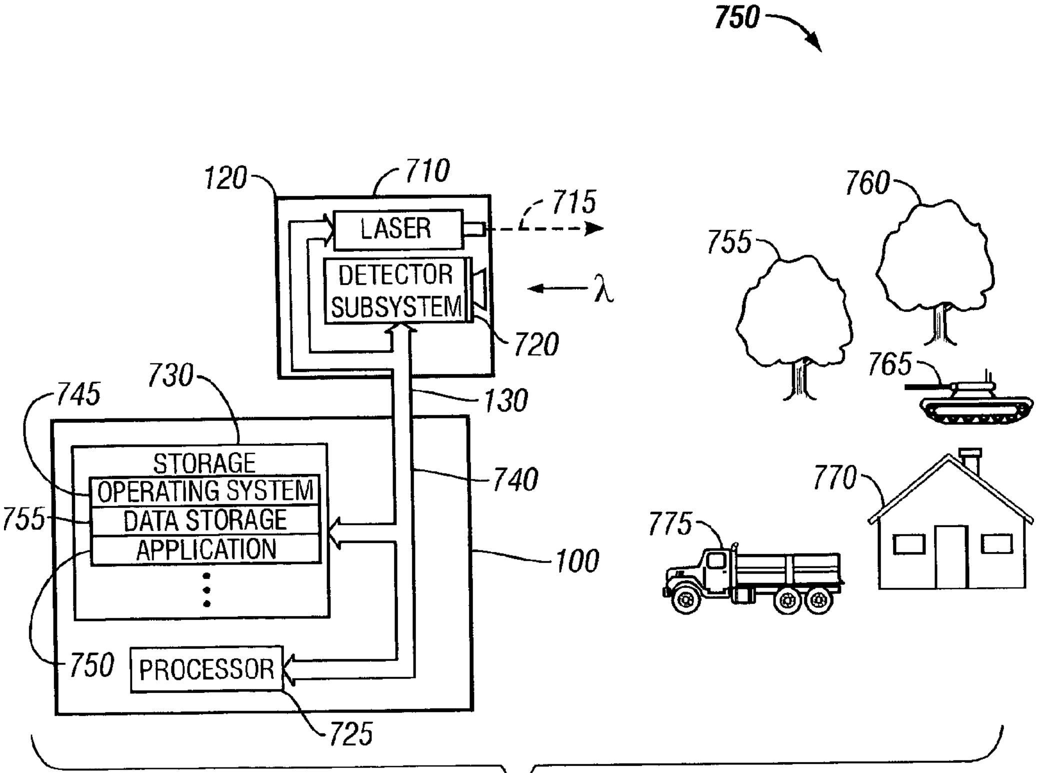

750
120
710
LASER
715
DETECTOR SUBSYSTEM
λ
720
130
730
745
STORAGE
OPERATING SYSTEM
DATA STORAGE
APPLICATION
755
740
100
750
PROCESSOR
725
755
760
765
770
775

FIG. 7

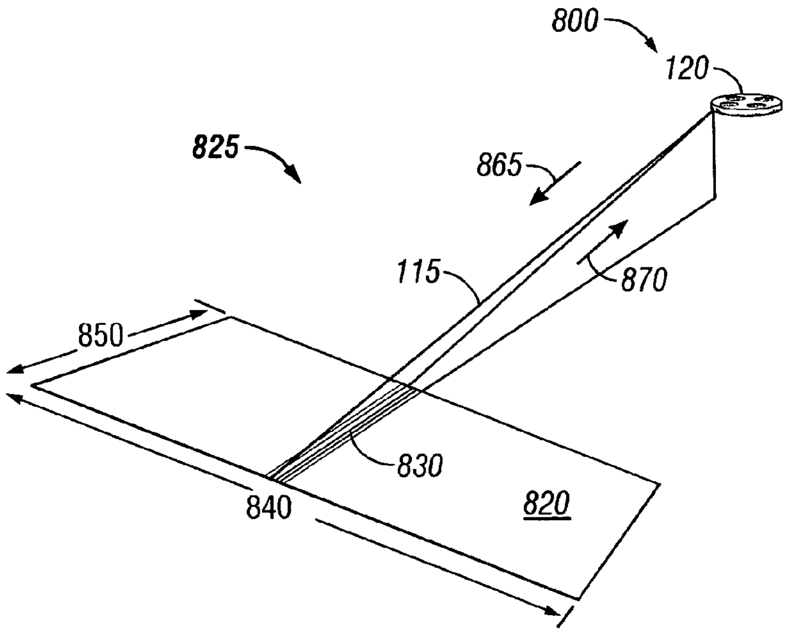

800
120
825
865
115
870
850
830
840
820

FIG. 8

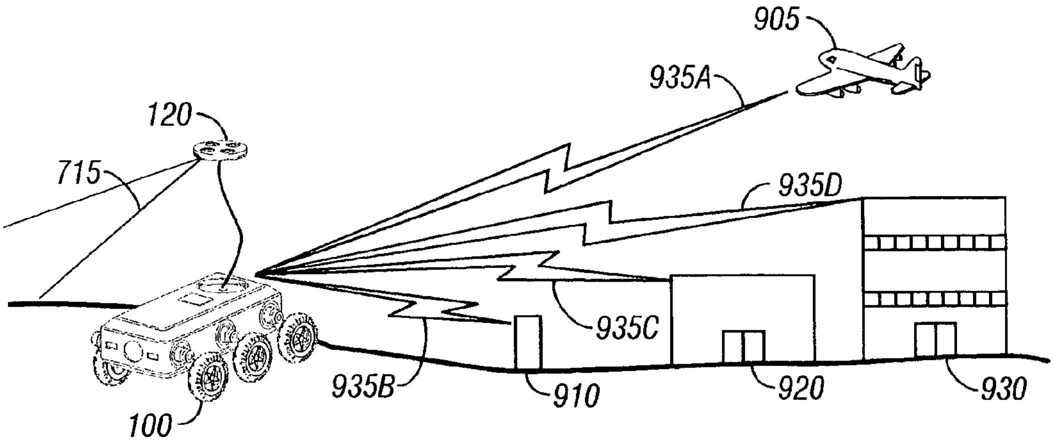

905
935A
120
715
935D
935C
935B
910
920
930
100

FIG. 9

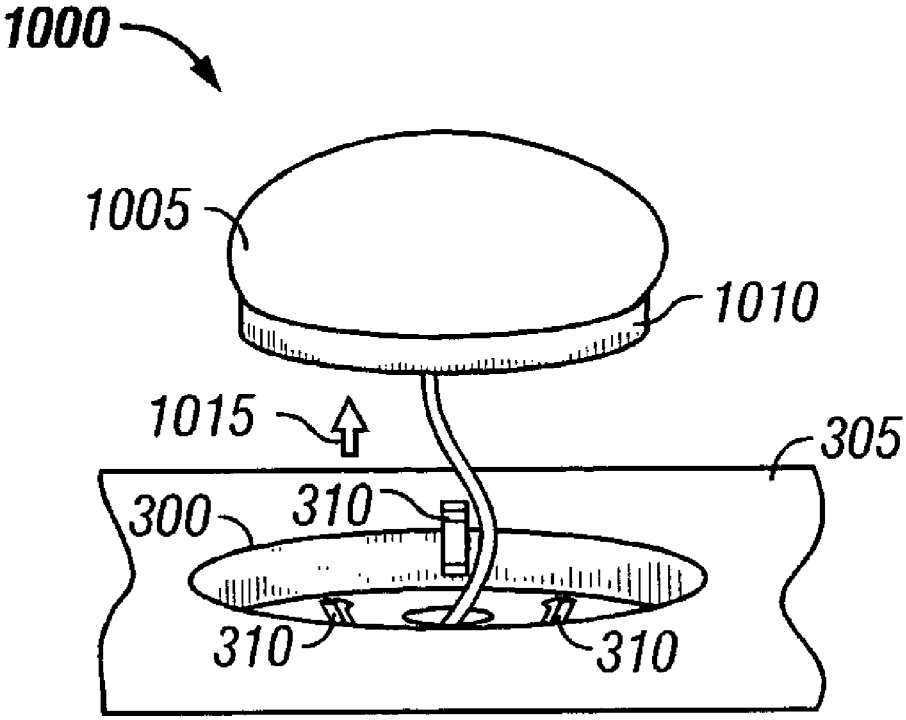


FIG. 10A

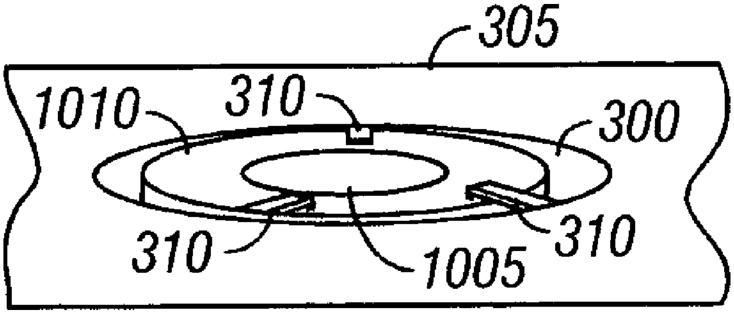


FIG. 10B

VIRTUAL SENSOR MAST

We claim the earlier effective filing date of co-pending U.S. Provisional Application Ser. No. 60/449,271, entitled "Unmanned Ground Vehicle," filed Feb. 21, 2003, in the name of Michael S. Beck, et al., for all common subject matter.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains to remote sensing for ground vehicles and, more particularly, to a technique for achieving a higher vantage point from which the sensing occurs.

2. Description of the Related Art

One significant challenge presented by unmanned, robotic vehicles is situational awareness. Situational awareness includes detection and identification of conditions in the surrounding environment. Robotic vehicles typically carry a variety of instruments to remotely sense the surrounding environment. Commonly used instruments include technologies such as:

acoustic;

infrared, such as short wave infrared ("SWIR"), long wavelength infrared ("LWIR"), and forward looking infrared ("FLIR");

optical, such as laser detection and ranging ("LADAR").

Typically, several different instruments are used to employ more than one of these technologies since each has advantages and disadvantages relative to the others.

A common limitation for any of these technologies is the vantage point of the instrument. For instance, the height of the vantage point inherently limits the field of view for any sensor, which is particularly problematical for long-range sensors. The height of the vantage point also affects the perspective of the data collected. For instance, the perspective afforded by a higher vantage point facilitates identifying negative obstacles (e.g., ditches) and cul-de-sacs.

One approach to this problem is to mount at least some of the sensors relatively high on the body of the vehicle. Sensors for which this limitation is particularly problematical are sometimes mounted to a mast extending upwardly from the vehicle. However, simply positioning the sensors high on the vehicle's body or on a sensor mast may offer only marginal improvement. Mounting sensors atop a mast may complicate maneuverability for the vehicle and or have other adverse consequences, such as increasing the vehicle's profile.

Another approach places the sensors on an airborne vehicle that communicates wirelessly with the ground vehicle. The airborne vehicle may be, for instance, a teleoperated or robotic helicopter that senses the environment and wirelessly transfers the data to the ground vehicle. This approach can greatly enlarge the field of view, since the altitude of the airborne vehicle is independent of the ground vehicle. However, this approach also manifests several drawbacks. For instance, because the airborne vehicle is independent of the ground vehicle, it must provide its own power, which adds size, weight, and complexity to the airborne vehicle. Also, since the airborne vehicle communicates wirelessly, precautions must be taken when several are used contemporaneously in the same general area. The independence of the airborne and ground vehicles also introduces uncertainties in the data caused by uncertainties in the relative positions of the vehicles.

The present invention is directed to resolving, or at least reducing, one or all of the problems mentioned above.

SUMMARY OF THE INVENTION

The invention includes a virtual sensor mast for a ground vehicle and a method for operating a ground vehicle using a virtual sensor mast. The virtual sensor mast comprises an unmanned airborne vehicle capable of lifting itself from the ground vehicle upon deployment therefrom; a sensor suite mounted to the unmanned airborne vehicle; and a tether between the unmanned airborne vehicle and the ground vehicle over which the sensor suite is capable of communicating sensed data upon deployment. The method comprises elevating a tethered unmanned airborne vehicle from the ground vehicle to a predetermined height; sensing environmental conditions surrounding the ground vehicle; and terminating the deployment.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

FIG. **1** depicts a ground vehicle employing a virtual sensor mast in accordance with the present invention;

FIG. **2** depicts a portion of a tether management system such as may be employed in the embodiment of FIG. **1**;

FIG. **3**A–FIG. **3**B illustrate the stowage and deployment of the unmanned airborne vehicle in the embodiment of FIG. **1**;

FIG. **4**A–FIG. **4**B illustrate the stowage and deployment of the unmanned airborne vehicle in the embodiment of FIG. **1** in a fashion alternative to that in FIG. **3**A–FIG. **4**B;

FIG. **5**A–FIG. **5**H illustrate one particular embodiment of a ducted fan with which the unmanned airborne vehicle may be implemented in one particular embodiment, wherein:

FIG. **5**A is a view in perspective of an aerobotic single-engine ducted VTOL aircraft embodying the principles of the invention, looking slightly from above;

FIG. **5**B is another view in perspective, looking from a higher viewpoint, of the aircraft of FIG. **5**A;

FIG. **5**C is a top plan view thereof;

FIG. **5**D is a view in section taken along the line **4**—**4** in FIG. **5**C, with one spoiler shown vertical and one horizontal;

FIG. **5**E is an enlarged fragmentary view in perspective of a portion of the aircraft of FIG. **5**A, looking from below, showing a portion of the camber vane control;

FIG. **5**F is a simplified fragmentary view in elevation of one duct portion, showing two non-activated camber vanes;

FIG. **5**G is a view similar to FIG. **5**F with the camber vanes actuated;

FIG. **5**H is an enlarged fragmentary view in perspective of a portion of the aircraft of FIG. **5**A, showing a pair of spoilers and their control linkages;

FIG. **6** is a view in perspective of a modified form of the unmanned airborne vehicle of FIG. **5**A–FIG. **5**H; embodying the invention, having four propellers and four ducts and no spoilers;

FIG. **7** illustrates the acquisition of data in one particular embodiment;

FIG. **8** depicts the operation of an active LADAR system on the unmanned airborne vehicle of the unmanned ground vehicle in FIG. **1** in the illustration of FIG. **7**;

FIG. **9** illustrates several options for controlling the ground vehicle of FIG. **7**; and

FIG. **10**A–FIG. **10**B depict an embodiment alternative to that illustrated in FIG. **1**.

While the invention is susceptible to various modifications and alternative forms, the drawings illustrate specific embodiments herein described in detail by way of example. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers'specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort, even if complex and time-consuming, would be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

FIG. **1** illustrates an unmanned ground vehicle ("UGV") **100** employing a virtual sensor mast **110** in accordance with the present invention. The virtual sensor mast **110** comprises an unmanned airborne vehicle ("UAV") **120** communicating with the ground vehicle over a tether **130**. The UAV **120** includes a suite of sensors (not shown) discussed more fully below. The UAV **120** is shown deployed, i.e., elevated from the ground vehicle **100**, and may be stowed in a fashion discussed more fully below. The UAV **120** is a vertical takeoff and landing ("VTOL") vehicle, and is electrically powered over the tether **130** in the illustrated embodiment. A tether management system **200**, partially shown in FIG. **2**, is housed in the chassis **140** of the UGV **100** and manages the tether **130** as the UAV **120** is deployed and retrieved in a manner described more fully below. The tether management system **200** includes an electric motor and winch **205** and a drum **210** used to control the tension/spooling of the tether **130**. Variable stops can be achieved through freezing the drum **210** at the desired locations using sensory feedback (drum encoder, string potentiometer or infrared/ultrasonic sensor, none shown). Note that some embodiments may employ rollers or bearings around the lip **215** of the opening **220** through which the tether **130** is deployed and retracted.

Referring again to FIG. **1**,the UGV **100**, in the illustrated embodiment, is a six-wheeled vehicle including six wheel assemblies **150** (only one indicated) that comprise a suspension system for the UGV **100**. Each wheel assembly **150** includes an airless wheel **152** fabricated from a composite material and mounted to an independently articulated suspension arm **154**. Note that alternative embodiments may employ a commercial-off-the-shelf ("COTS"), all terrain vehicle ("ATV") tire, e.g., the Dunlop KT401C. The articulated suspension arms **154** are capable of rotation facilitating extreme mobility and obstacle negotiation as well as inverted operability. A rotary magnetorheological ("MR") damper **156**, facilitated by substantially real time damping control, is mounted coaxially with the arm pivot **158**. Each suspension arm **154** has a compliant rotary suspension with controllable damper **156** to absorb impacts and provide for sensor stability. Air springs (not shown) and double wishbone suspension (also not shown) at each wheel **152** provide a lightweight, robust and fail-soft suspension.

Each suspension arm **154** has a high torque rotation actuator (not shown) that enables the UGV **100** to perform maneuvers not ordinarily possible in manned vehicles. The wheel assemblies **150** enable the UGV **100** to:

"walk" over large obstacles;
vary height/ground clearance;
adapt steering and suspension dynamics on the fly; and
safely accommodate high impact velocities.

Individual articulation of the wheel assemblies **150** further enhances skid steering through footprint variation. Survivability and stability are enhanced by squatting the UGV **100** to reduce presented area and lower center of gravity ("CG"), enhance mobility in soft terrain and improve sensor visibility via front elevation.

Each wheel **152** includes a two-speed transmission (not shown) embedded in the hub to allow for high and low speed operation with hub drive motors (not shown). Each suspension arm **154** is driven by an independent, dedicated drive. The assembly of wheel, drive motor, switching hub, etc., eliminates (or at least reduces) the need for mechanical brakes. Each wheel **120** contains a hub drive motor (not shown) and integrated gear set (not shown) that allow wheel-to-wheel speed variations and enhanced skid steering. Each articulated suspension arm **125** houses a hub motor controller (not shown). This improves reliability through the reduction of slip rings (not shown) required in the shoulder joint, or arm pivot, **158** between the suspension arm **154** and the chassis **140** and provides redundancy. Each suspension arm **152** becomes an independent power system providing tractive effort from a common electrical, direct current ("DC")-link. A failure in a motor controller or motor therefore may not disable the UGV **100**.

The chassis **140** provides the structure for vehicle integration with desirable stiffness, payload protection and thermal management. Important design considerations include: structural strength; stiffness; survivability; weight; stiffness-to-weight ratio; damage tolerance; reparability; corrosion resistance; modularity; and optimized component packaging and integration. In the illustrated embodiment, the chassis **140** comprises a shell (not indicated), or frame, with integral bulkheads (not shown) covered by a plurality of panels (also not indicated). The shell of the chassis **140** is comprised of graphite/epoxy sheets (not shown) sandwiching an aluminum honeycombed core (not shown). The panels are reinforced by KEVLAR™ to improve puncture and abrasion resistance. All points of attachment where significant loads are transferred are reinforced with glass fiber/epoxy inserts (not shown) and high-density foam (not shown).

The chassis **140** also houses charge-coupled device ("CCD") and acoustic sensors (not shown) located around the periphery of the chassis **105** for situational awareness. The illustrated embodiment employs four Emkay WP-3502 acoustic sensors, four Nevada Systems NSI-5000c CCD cameras, eight near field MASSA M-5000/220 ultrasonic sensors, and eight far field MASSA E-220B/26 ultrasonic sensors. Data generated from these sensors may be used to augment or may be used in conjunction with data generated from sensors aboard the virtual sensor mast **110**. However, this is not necessary to the practice of the invention and these sensors may be omitted in some alternative embodiments.

The chassis **140** houses a power plant (not shown) that provides power and charges batteries (also not shown) used in powering various drives and other electrically powered components, including powering and/or recharging the UAV

120. More particularly, the illustrated embodiment employs a series hybrid power plant comprising a commercial, off-the-shelf-based single cylinder air-cooled Direct Injection ("DI") diesel engine (not shown) and a Variable Reluctance Motor ("VRM") used in conjunction with two parallel strings of lithium-ion batteries (not shown). More particularly, this power plant consists of a four-stroke, direct injection compression ignition (diesel) engine power plant, a motor/generator, a power distribution management system, an energy storage system, and in-hub variable reluctance motors. The VRM is efficient at high torques and low speeds, the exact operating envelope of the UGV **100** during silent motion.

A power management system (not shown) enhances battery life by efficiently managing the energy distribution throughout the vehicle. The energy from the batteries is converted to the appropriate DC level using bi-directional converters. The DC-link supports system efficiency by level-ranging from module voltage to 400 VDC depending on the speed of the vehicle. During engine start, the bi-directional inverter (generator controller) provides energy to start the diesel engine. Thereafter, the diesel engine is used to support the system and drive loads. The bi-directional converters reverse the energy flow from the DC-link to the battery packs and system loads. If the demand for the loads exceeds the engine generator capability, the bi-directional inverters provide the additional energy required from the batteries. Another function of the bi-directional inverter is to convert land power (i.e., 115, 208, and 240 VAC) to charge the batteries between missions or power the system for training, and maintenance.

Some embodiments include a mast base enclosure (not shown) housing a majority of the payload (also not shown) and centered in the front of the UGV **100**. The mast base is pivoted in the center of the UGV **100** and has a total rotational travel of 180 degrees to allow it to be deployed vertically from the top or bottom of the UGV **100**. In these embodiments, the portion of the chassis **140** on either side of the mast base enclosure is referred to as the "sponson." Much of the volume of each sponson is available for payload. There are three areas in the chassis **140** allocated for fuel and battery storage. One area is in the center of the UGV **100** and the other two are in the sponsons. The majority of the vehicle control and power electronics are located above the center fuel tank or in the areas on either side of the mast pivot in these embodiments.

Note that the UGV **100** of the illustrated embodiment is but one particular implementation. The present invention may be employed in virtually any suitably modified and/or equipped ground vehicle, whether manned or unmanned and regardless of whether it is robotic. For instance, the invention may be employed with wheeled vehicles whose suspension is not independently articulable, e.g., the HUMVEE. The invention may be employed on tracked vehicles, e.g., the Bradley fighting vehicle. The invention may also be employed on vehicles that are both wheeled and tracked, e.g., the now retired M-16 and M-3 half-tracks of World War II vintage. Furthermore, the invention is not limited to deployment on military vehicles, and may find applicability in civilian contexts.

The UAV **120** of the illustrated embodiment is a VTOL aircraft including one or more ducted fans. The particular embodiment of FIG. **1** actually employs four ducted fans **162***a*–**162***d*, but the number of ducted fans is not material to the practice of the invention. The UAV **120** may be deployed and stowed, as is best shown in FIG. **3**A–FIG. **3**B, in a recess **300** in the surface **305** of the chassis **140** of the UGV **100**. When stowed, as shown in FIG. **3**B, a plurality of clamps **310** secure the UAV **120** in the recess **300**. To deploy the UAV **120**, the clamps **310** can be released and the ducted fans **162***a*–**162***d* activated until the UAV **120** elevates itself from the UGV **100**, as indicated by the arrow **320**. As the UAV **120** elevates, the electric motor and winch **205** of the tether management system **200**, shown in FIG. **2**, release the drum **210** so that the tether **130** plays out.

The UAV **120** elevates to some desired altitude to remotely sense the environment in which the UGV **100** is situated. Typically, the UGV **100** will not be moving during the deployment, or will move only very little. Also, the deployment will typically be of relatively short duration. Once the remote sensing is completed, the UAV **120** is retracted back into the recess **300**, as indicated by the arrow **322**. Note that the recess **300** may be oversized, as shown, and that the positions of the clamps **315** may be so dimensioned as to facilitate the retraction. To terminate the deployment, the electric motor and winch **205** can spool the drum **210** with force sufficient to overcome the lift exerted by the ducted fans **162***a*–**162***d*. The ducted fans **162***a*–**162***d* may be powered down some to facilitate retraction. The tether **130** is attached to the UAV **120** in a position selected, in part, to facilitate the retraction, as well. As the UAV **120** retracts into the recess **300**, the clamps **310** engage the UAV **120** to secure it in the recess **300** until the next deployment. Note that the clamps **310** may be omitted in some embodiments where the recess **300** is deep enough.

The UAV **120** may be stowed and deployed from the UGV **100** in any number of ways, some of which will depend on the implementation of the UAV **120**. FIG. **4**A–FIG. **4**B illustrate a technique for stowing and deploying the UAV **120** alternative to that shown in FIG. **3**A–FIG. **3**B. In this implementation, the UAV **120** is stored in and deployed from a "basket" **400**. The deployment and retraction are otherwise the same.

FIG. **5**A–FIG. **5**H illustrate a ducted fan UAV **500**, that can be modified from that disclosed and claimed in United States Letters Patent No. 4,795,111, issued Jan. 3, 1989, to Moller International, Inc., as assignee of the inventor Paul S. Moller ("the '111 patent"). The particular ducted fan of the '111 patent can, as will be discussed further below, be readily modified to implement the present invention. Note that this particular UAV includes only a single ducted fan, rather than the four of the UAV **120** in FIG. **1**. The limited number of ducted fans in the illustrated embodiment will improve the clarity and coherence of the discussion. However, an embodiment employing four such ducted fans will be discussed further below.

More particularly, FIG. **5**A–FIG. **5**H show a single-engine ducted fan VTOL vehicle **500** with a propeller **511** and a duct **512**. The propeller **511** is mounted horizontally on a shaft **513** and is powered by a single engine **514** below it. The illustrated propeller **511** has two blades **515** and **516** and a nose **517**. The circular duct **512** has a curved flange **518** at its upper end and has a planar lower edge **519**. As shown in FIG. **5**A–FIG. **5**B the duct **512** may have a support member **520** with a hollow bottom or base ring **521** and four support columns **522**. The ring **521** also serves as a muffler and is connected by a pair of vertical exhaust tubes **523** to the exhausts from the engine **514**, there being two such exhaust tubes for a two-cylinder engine **514**. The exhaust gas goes down the tubes **523** into the ring **521** and passes out from the ring **521** at exhaust openings **524**, spaced around the ring **521** at distances beginning about 90° away from the tubes **523** and extending downwardly at about 45°.

Mounted on the exterior face of the duct **512** is a series of control devices and other instrumentation, each a type of electronic device, including a detector and receiver **526**, and various programmed control initiators **527**, which control the engine or motor **514** and the various lever systems described below. In the illustrated embodiment, the motor **514** is an electrical motor powered by the UGV **100** over the tether **130** in a manner described more fully below.

In the duct **512** are twelve fixed vanes **531**, **532**, **533**, **534**, **535**, **536**, **537**, **538**, **541**, **542**, **543**, and **544**. The eight identical vanes **531**, **532**, **533**, **534**, **535**, **536**, **537**, and **538** are disposed along two mutually perpendicular axes. That is, there are four vanes **531**, **532**, **533**, **534** arranged as two diametrically opposite pairs **531**, **532** and **533**, **534** parallel to one diametral line **539**, shown in FIG. **5**C. There are two other diametrically opposite pairs of vanes **535**, **536** and **537**, **538** parallel to a diametral line **541** perpendicular to the line **539**. Each pair of vanes forms a generally rectangularly shaped duct segment and adjacent pairs form generally quadrant shaped duct segments. These eight vanes **531**–**538** are preferably not simply vertical planes but are preferably shaped as shown in FIG. **5**F–FIG. **5**G, and they each have a variable-camber flap **545** or **546** attached to their lower or trailing edge.

For yaw control, or control about the vertical axis, the flaps **545** and **546** of all eight of these vanes **531** through **538** move together in the same rotational direction, resulting in torque about the vertical axis. For translational control, the flaps **545** and **546** of two diametral pairs move together, shown in FIG. **5**G, while the flaps **545** and **546** of the other diametral pairs either do not move or move in a direction or directions. As a result, a force is generated for accelerating the vehicle **500** horizontally at a speed up to a point where its aerodynamic drag equals its ventable translational force

Preferably, each camber flap **545**–**546** is equal in area to its respective vane **531**–**538**. As a result the center of pressure of the vane-flap combination occurs at the three-quarter chord position C back from the leading edge L, i.e., near the center of the camber flap **545** or **546**, and this is where the center of pressure of the vanes occurs. This center of pressure is kept as close as possible to the position along the vertical-axis occupied by the center of gravity of the vehicle **500** and is preferably within the limits of the vertical extremities of the flaps **545**–**546**.

Each pair of flaps **545** and **546** is joined together by a tie rod **547** having a clevis clip **548** at each end pivoted to it by a pin **549**, controlled, as shown in FIG. **5**E, by a servomotor **550**. The servomotor **550** is actuated by a potentiometer **551**, and both are in a foam-rubber fitted housing **552**. The servomotor **550** acts on the tie rod **547** through the vane control arm **553**, having a sleeve **554** held on a servomotor shaft **555** by a recessed Allen-head screw **556**. The arm **553** may act through a ball-and-socket joint **557** on a drag linkage **558**, which operates on the tie rod **547** through another ball-and-socket joint **559**.

The other four vanes **541**, **542**, **543**, and **544**, shown in FIG. **5**B, are rigid and extend in from the wall of the duct **512** to bisect the right angles made by the mutually perpendicular vanes **532**, **537** and **538**, **534** and **533**, **536** and **537**, **531**, shown in FIG. **5**C. In other words the vanes **541**, **542**, **543**, and **544** lie at an angle of 45° to the eight diametral vanes **532**, **537** and **538**, **534** and **533**, **536** and **535**, **531**. Preferably, these four vanes **541**, **542**, **543**, and **544** are not simply vertical planes but are shaped like the rigid upper portions of the vanes shown in FIG. **5**F–FIG. **5**G (but without the attachment of variable-camber vanes).

Between the vanes **531** and **532** is a generally rectangular duct segment or passage **561**; between the vanes **533** and **534** is a diametrically opposite rectangular passage **563**. At right angles to these openings are a rectangular passage **564** between the vanes **535** and **536** and a rectangular passage **562** between the vanes **537** and **538**. Thus, between the vanes **532** and **537** is a quadrant divided into two equal passages **565** and **566** by the vane **541**; between the vanes **538** and **534** is a quadrant shaped duct segment divided into two equal passages **567** and **568** by the vane **542**; between the vanes **533** and **536** is a quadrant shaped segment bisected into two passages **569** and **570** by the vane **543**; and between the vanes **535** and **531** is a quadrant shaped segment bisected into two passages **571** and **572** by the vane **544**.

Each vane **541**, **542**, **543**, and **544** preferably supports a pair of spoilers **575**, **576** or **577**, **578** or **579**, **580** or **581**, **582**, one for each passage **565**, **566**, **567**, **568**, **569**, **570**, **571** and **572**. The spoilers **575**–**582** each have a circular-arc outer rim **583** concentric with the duct **512** and are otherwise generally trapezoidal in shape to fill most of the outer portion of their respective passages **565**–**572** when in the fully closed or horizontal position, as depicted in FIG. **5**B–FIG. **5**C. When rotated down to their fully open or vertical position, they lie generally parallel to their respective vanes **541**–**544**, as shown at **581** in FIG. **5**D, and take up very little room in the passages **565**–**572**.

The spoilers **575**–**582** are each supported by their associated vanes **541**–**544** through a tension bracket **584** and are operated, as shown in FIG. **5**H, via a remotely activated system embodying a potentiometer **585** supported with a servomotor **586** inside a housing **587**. The servomotor **586** operates, like the servomotor **550**, through a linkage arm **588** and a drag linkage **589** having a ball-and-socket joint at each end, and a lever arm **590** that rotates on shaft **591**.

In each quadrant, a single servomotor **586** operates the pair of spoilers **575**, **576**, etc.; so that in each quadrant the spoilers are paired. Moreover, the pivot axis of each spoiler lies along and coincides with the position where the torque on its spoilers is minimized as a function of its angular position; thereby the torque required to deploy that pair of spoilers is reduced, and the size of the servomotors **586** is kept small. Since each spoiler **575**–**582** has its surface concentrated near the duct wall, the resulting control moment is maximized. Each spoiler may be made from lightweight wood, to minimize its inertia and provide rapid response to its servomotor **586**.

The functional mixing of yaw and translation forces is preferably done electronically by the control circuits **527**, with the vehicle **500** employing eight separate servomotors **550** and **586** for control. Thus, there are four servomotors **550** for yaw or translational controls and four servomotors **586** for pitch-and-roll controls. One servomotor controls one parallel set of yaw vanes or one pair of spoilers.

This system for controlling the flight of the vehicle **500** has the additional capability of being able to trim the vehicle **500** into a non-vertical position and holding that position through the use of translational control power. This may be desirable when a rigidly attached TV camera is used and is directed in the plane of vision by, for instance, gimballing the vehicle rather than gimballing the camera.

The principles of the UAV **500** can be extrapolated, as shown in FIG. **6**, for use with multiple ducted fans in a single UAV, as in the case of the UAV **120** in FIG. **6**. If the UAV employs a plurality of ducts, as in the case of the vehicle **600** shown in FIG. **6**, then the spoiler approach can be augmented or even replaced by a system that alters the thrust in the individual ducts, either by individual fan pitch control or individual throttle engine control.

The illustrated UAV, whether utilizing a single-engine ducted fan (e.g., FIG. **5**A–FIG. **5**H) or utilizing a plurality of such ducted fans (e.g., FIG. **6**), provides pitch-and-roll control seperate from translational control. The spoiler system is automatically driven by an on-board inertial reference system (not shown), and the spoilers are deployed only for the purpose of keeping the vehicle lift axis parallel to or coincident with the gravitational axis. The moment of inertia about the pitch-and-roll axis and the response time of the spoilers are both minimized, so that only very low forces are required from the spoilers **575**–**576**, **577**–**578**, **579**–**580**, **581**–**582**. The result is that there is little loss of lift; hence, there is little coupling between the pitch-and-roll control and the heave or vertical movement. The vehicle **500** may be trimmed to level, but trimming is not used for controlling maneuvers about the pitch-and-roll axis.

The spoilers **575**–**576**, **577**–**578**, **579**–**580**, **581**–**582** are paired in each quadrant. This ensures that little or no torque or force is generated which might rotate the vehicle **500** about the vertical or yaw axis when the spoilers **575**–**576**, **577**–**578**, **579**–**580**, **581**–**582** are employed. The pivot axis of each spoiler vane coincides with the position where the torque on the spoiler is minimized as a function of its angular position. This positioning reduces the amount of torque required to deploy the pair of spoilers and hence reduces the size of the servomotors required. Most of the spoiler surface is concentrated near the maximum duct diameter, in order to maximize the resulting control moment. Preferably, the spoilers **575**–**576**, **577**–**578**, **579**–**580**, **581**–**582** are made of extremely light material in order to reduce their inertia and to obtain rapid spoiler response with reduced servomotor power.

Translational control is obtained by use of a flexible vane instead of a pivoted rigid vane. In a deflection vane system, it is desirable to recognize that a rigid vane generates two major problems when used to deflect a slip stream:

(1) The forces generated by swinging a rigid vane are highly nonlinear relative to the changing angle of the vane, and particularly when the aircraft is near the stall condition.

(2) The stall condition is reached by rigid vanes at fairly low angles of vane deflection, generally less than 15°. However, for significant translational forces, such as those which are required to move a vehicle of this type at a velocity greater than one-third of the slip stream velocity, the slip stream deflection required becomes significant and is greater than 15°.

Therefore, the illustrated UAV employs a variable-camber vane or flap, which is attached to the trailing edge of fixed anti-torque vanes that serve to remove the swirl introduced by the fan.

The UAV thus obtains translational control by redirecting the slip stream with vanes **575**–**576**, **577**–**578**, **579**–**580**, **581**–**582** that are provided with flexible camber portions or flaps extending downwardly from an upper fixed rigid portion, and the vanes are mounted so that the center of lift or force providing the transverse force is at or as close as possible to the center of gravity of the vehicle. This mounting ensures that deflection of the variable-camber vane or flap does not generate significant moments about the center of gravity; such moments, if generated, would have to be overcome by the spoiler system. Small coupling moments are automatically dealt with by the spoiler system and result only from forces produced about the pitch-and-roll axis, due to translational control.

If the flexible portion of the vane is equal in size to the rigid upstream portion, then the transverse force (or center of pressure) of the rigid-flexible deflector vane occurs at approximately the three-quarter chord position back from the leading edge. Put another way, the center of pressure or lift appears to occur near the center of the flexible portion of the vane. In fact, this position is a function of the amount of vane deflection. For greater deflections this position is probably correct. For small deflections this center of pressure will be farther forward. Preferably, the center of left on the vane is at the center of gravity of the vehicle, on the vertical axis.

The variable-camber vanes act like a flap (or aileron) on a wing. Such a flap may involve comparatively small forces and be small in size relative to the forces it can generate. Thus, when a variable-camber vane system employs two or more vanes in parallel, a cascade vane effect is created. This cascade effect continues to deflect the slip stream up to 90°, if that should be necessary. However, it is unlikely that deflection greater than 30° will ever be required.

More succinctly summarized, there is least one ducted fan, comprising power means, a horizontally mounted fan connected to and driven by the power means for causing a vertically and downwardly directed airstream, and a cylindrical duct that extends around and beneath the fan, for confining the airstream. In the duct is a vane system comprising two mutually perpendicular pairs of diametrically opposite generally rectangularly shaped duct segments, each defined and bounded by a pair of generally vertical stationary walls extending across the duct parallel to a diametral line thereacross. Each pair of these walls also defines one boundary of a quadrant shaped duct segment located between adjacent wall pairs. Each duct segment forming a wall includes an upper, rigid portion having a variable-camber flap portion affixed to its lower extremity. A first set of remotely controlled servo motors is employed for varying the camber of each of the flaps. In each pair of variable vanes, the flap camber is at all times the same in amount and direction for both flaps.

The UAV disclosed in the ’111 patent can be readily modified to accommodate and take advantage of the present invention. The UAV of the ’111 patent includes an antenna for radio communication, which is unnecessary in the present invention. Thus, the antenna and the transmitter/receiver associated with radio communication are eliminated from the implementation of the UAV **120**. A connection for the tether **130** will similarly need to be added. Furthermore, the UAV **120** will typically fly at lower altitudes than the UAV of the ’111 patent, and can receive power from the UGV **100** over the tether **130**. Thus, the internal combustion engine (and gas tank) for the UAV of the ’111 patent are replaced by a lighter electric motor. The invention admits wide variation in the sensing capabilities that may be implemented on the UAV **120**. Further modification may be desirable to accommodate different sensing capabilities, as will be discussed further below.

Note that, in the illustrated embodiment, the UAV **120** is intended to hover above the UGV **100** while the UGV **100** is stopped. The UAV **120** consequently need only provide vertical lift, and need not provide horizontal propulsion. Thus, the weight and complexity of the UAV **120** can be reduced relative to conventional UAVs. Note also that in the illustrated embodiment, power is provided to the propulsion systems and sensor packages aboard the UAV **120** over the tether **130** from the UGV **100**. This results in further savings in weight and complexity since the UAV **120** need not provide its own power. The UAV **120** and/or its sensor suite can also be recharged from the UGV **100** over the tether **130** and/or recharged and/or refueled from the UGV **100** when not deployed.

Returning to FIG. **1**, the tether **130** may be any suitable transmission medium known to the art. For instance, in the illustrated embodiment, the tether **130** is comprised of one or more optical fibers cabled together. Alternative embodiments may employ coaxial cables or twisted wire pairs. The present invention is not limited by the implementation of this aspect. However, the characteristics of various media may affect the design of some implementations in ways well known to the art. For example, some media do not spool as well or as tightly as do other media, and the dimensions of the drum **210**, shown in FIG. **2**, will be sized accordingly. In some embodiments, the UAV **120** may receive power from the UGV **100** over the tether **130**. The tether **130** in such embodiments then includes a power lead over which the UAV **120** receives power and the tether becomes an umbilical.

Returning once again to FIG. **1**, the UAV **120**, when deployed, remotely senses the environment in which the UGV **100** is situated. As was mentioned above, the UAV **500** illustrated in FIG. **5**A–FIG. **5**H is equipped with a suite of sensors including a detector and receiver **526**. The type and number of sensors will be implementation specific, and may employ almost any type of remote sensing technology. In one proposed implementation, illustrated in FIG. **7**, the remote sensing technologies includes an active LADAR system and a passive infrared system. Note, however, that the number and type of sensors in the sensor suite will be implementation specific. For instance, in some embodiments, the sensor suite may comprise a single, passive IR sensor. One particular embodiment is described immediately below.

In the proposed embodiment of FIG. **7**, the UAV **120** includes a laser **710** that produces a laser signal **715**, a detector subsystem **720**, a processor **725**, and an electronic storage **730** communicating via a bus system **740**. The processor **725** may any kind of processor, such as, but not limited to, a controller, a digital signal processor ("DSP"), or a multi-purpose microprocessor. The electronic storage **730** will probably be magnetic (e.g., some type of random access memory, or "RAM", device), but may also be optical, in whole or in part, in some embodiments. The storage **730** may also include removable storage (not shown), such as a floppy magnetic disk, a zip magnetic disk, or an optical disk. The bus system **740** may employ any suitable protocol known to the art to transmit signals. Note that the bus system **740**, in this particular embodiment, transmits over the tether **130**. Particular implementations of the laser **710**, laser signal **715**, and detector subsystem **720** are discussed further below.

The processor **725** controls the laser **710** over the bus system **725** and processes data collected by the detector subsystem **720** from an exemplary scene **750**. The scene **750** includes trees **755** and **760**, a military tank **765**, a building **770**, and a truck **775**. The tree **755**, tank **765**, and building **770** are located at varying distances from the system **700**. Note, however, that the scene **750** may have any composition. One application of the remote sensing system **700**, as shown in FIG. **7**, may be to detect the presence of the tank **765** within the scene **750**. A second application may be to detect objects such as the trees **755**, **760**, or negative obstacles (not shown). The processor **725** operates under the direction of the operating system **745** and application **750** to fire the laser **710** and process data collected by the detector subsystem **720** and stored in the data storage **755** in a manner more fully described below.

The operation of the LADAR system aboard the UAV **120** is conceptually illustrated in FIG. **8**. The LADAR system includes the laser **710** of FIG. **7** as well as some portions of the detector subassembly **720**. The LADAR system collects three-dimensional data from a field of view **825**, shown in FIG. **8**, within the scene **750**, shown in FIG. **7**. The laser signal **715** is transmitted by the laser **710** on the UAV **120** to scan a geographical area called a scan pattern **820**, shown in FIG. **8**. Each scan pattern **820** is generated by scanning elevationally, or vertically, several times while scanning azimuthally, or horizontally, once within the field of view **825** for the UAV **120** within the scene **750**, shown in FIG. **7**. The scan patterns are sometimes, and will be hereafter herein, referred to as "footprints." FIG. **8** illustrates a single elevational scan **830** during the azimuthal scan **840** for one of the footprints **820**. Thus, each footprint **820** is defined by a plurality of elevational scans **850** such as the elevational scan **830** and the azimuthal scan **840**. The velocity and depression angle of the sensor with respect to the horizon, and total azimuth scan angle of the LADAR system, determine the footprint **820** on the ground.

The laser signal **715** is typically a pulsed signal and may be either a single beam or a split beam. Because of many inherent performance advantages, split beam laser signals are typically employed by most LADAR systems. A single beam may be split into several beamlets spaced apart from one another by an amount determined by the optics package (not shown) aboard the UAV **120** transmitting the laser signal **715**. Each pulse of the single beam is split, and so the laser signal **715** transmitted during the elevational scan **850** in FIG. **8** is actually, in the illustrated embodiment, a series of grouped beamlets. The optics package aboard the UAV **120** transmits the laser signal **715** while scanning elevationally **850** and azimuthally **840**. The laser signal **715** is continuously reflected back to the UAV **120**, which receives the reflected laser signal through the detector subsystem **820**.

While the LADAR system is operating, the detector subsystem **820** is also passively detecting infrared ("IR") radiation from the scene **850**. The IR detection is "passive" because the detected radiation does not result from energy introduced to the scene **850** by the sensors. The IR detection comprises a passive IR imaging of the scene **750** by a portion of the detector subsystem **720**. This produces a two-dimension passive image data set with each pixel (picture element) having passive intensity information corresponding to the magnitude of the passive IR energy collected for that pixel. In some embodiments, the same detector may be used for both the active LADAR and passive infrared detection, e.g., U.S. Pat. No. 6,323,941, entitled "Sensor Assembly for Imaging Passive Infrared and Active LADAR and Method for Same," issued Nov. 27, 2001, to Lockheed Martin Corp. as the assignee of the inventors Evans, et al.

Remote sensing techniques combining laser and infrared technologies are known to the art. See, e.g.:

U.S. Pat. No. 6,359,681, entitled "Combined Laser/FLIR Optics System," issued Mar. 19, 2002, to Lockheed Martin Corp. as the assignee of the inventors Housand, et al.;

U.S. Pat. No. 6,323,941, entitled "Sensor Assembly for Imaging Passive Infrared and Active LADAR and

- Method for Same," issued Nov. 27, 2001, to Lockheed Martin Corp. as the assignee of the inventors Evans, et al.;
- U.S. Pat. No. 5,345,304, entitled "Integrated LADAR/FLIR Sensor," issued Sep. 6, 1994, to Texas Instruments Incorporated, as the assignee of the inventor John E. Allen; and
- U.S. Pat. No. 4,771,437, entitled "Integrated Laser/FLIR Rangefinder," issued Sep. 13, 1988, to Texas Instruments Incorporated, as the assignee of the inventors Powell, et al.

Any suitable approach known to the art may be used to implement this aspect of the present invention. The LADAR system produces a LADAR image of the scene **750** by detecting the reflected laser energy to produce a three-dimensional image data set in which each pixel of the image has both z (range) and intensity data as well as x (horizontal) and y (vertical) coordinates. The IR system generates an IR image comprised of two-dimensional data.

Different embodiments may, however, employ different sensing capabilities depending on intended mission profiles. As those in the art having the benefit of this disclosure will appreciate, many engineering considerations go into the design of any given implementation. Weight and size of the sensors, for instance, should be considered in light of the lift capacity of the UAV **120**. Common types of remote sensors include a day camera, a FLIR sensor, a laser rangefinder, and a Global Positioning System ("GPS") sensor. Table 1, below, lists several sensors that might be employed in various embodiments according to a purpose for which their data may be employed. Note, however, that other sensors, sensor suites, and assemblies may be employed in alternative embodiments. For instance, some embodiments may employ TV cameras (day or night, i.e., low light cameras) and nuclear, biological and chemical ("NBC") sensors.

TABLE 1

Sensor Payloads

Purpose	Sensor
Targeting	SWIR, Indigo Merlin NIR w/50 MM Fixed FLIR - Long Lens, Indigo Alpha Target Designator, Litton - LLDR
Perception	Daylight Cameras - Watec 902S (Stereo) FLIR - Short Lens and Long Lens (Same as Above) LADAR, SRI
Other Sensors and Electronics	PC-104/CPU w/VGA (Real-time Devices) Sony EX470 Video w/18× Zoom Pan and Tilt (Directed Perception, PTU-46-17.5)

The data generated by the sensors aboard the UAV **120** is then transmitted over the tether **130** and the bus system **740**. The data is captured in the data storage **755** and processed by the processor **725** under the control of the application **750**. The data may be processed in any suitable manner known to the art, depending on the nature of the data collected and the reason for which it is collected. For instance, the data may be processed to identify obstacles for navigating the scene **750**. See, e.g.:

- Hebert, et al., "Evaluation and Comparison of Terrain Classification Techniques from LADAR Data for Autonomous Navigation," 23d Army Science Conference (December 2002), available over the Internet;
- Bellutta, et al, "Terrain Perception for DEMO III," Proceedings of the 2000 Intelligent Vehicles Conference, (2000);
- Macedo, et al., "Ladar-based Discrimination of Grass from Obstacles for Autonomous Navigation," ISER 2000 (2000); and
- Matthies, et al., "Obstacle Detection for Unmanned Ground Vehicles: A Progress Report," Robotics Research: Proceedings for the 7th International Symposium (1996).

However, in some embodiments, the data may be processed for reasons other than navigation. For instance, in military environments, the data might be processed through an automatic target recognition ("ATR") system to determine whether some obstacle is a vehicle and, if so, whether a friend or a foe. See, e.g.:

- U.S. Pat. No. 5,867,118, entitled "Apparatus for and Method of Classifying Patterns," issued Feb. 2, 1999, to Lockheed Martin Corp. as the assignee of the inventors McCoy, et al.;
- U.S. Pat. 5,893,085, entitled "Dynamic Fuzzy Logic Process for Identifying Objects in Three-Dimensional Data," issued Apr. 6, 1999, to Lockheed Martin Corp. as the assignee of the inventors Phillips, et al.;
- U.S. Pat. 5,852,492, entitled "Fused Lasar Range/Intensity Image Display for a Human Interpretation of Lasar Data," issued Dec. 22, 1998, to Lockheed Martin Corp. as the assignee of the inventors Nimblett, et al.;

These examples are illustrative only, and the list is not exhaustive. Other embodiments may process the data in still other ways for still other purposes.

The use of the tether **130** in the virtual sensor mast **110** imparts numerous advantages over conventional practice. The data may be more simply formatted since there is no danger of receipt by the wrong UGV **100**. The data is generally more free of noise because it is not broadcast wirelessly and because fewer instruments (i.e., no transmitter, no receiver) are needed. Consequently, the data is generally easier to process relative to data collected by conventional, untethered UAVs. At the same time, the data can be acquired at an aspect angle greater that that available from mast mounted sensor packages. Thus, it is relatively easier to identify negative obstacles (e.g., ditches) and cul-de-sacs relative to mast-mounted sensors. Deployment of the UAV **120** also permits the UGV **100** to hide the chassis **105** while peering over defilade positions, buildings and water. The additional height afforded by deploying the UAV **120** with the tether **130** also reduces multi-path error, which improves data quality and eases data processing.

In the illustrated embodiment, the UGV **100** can be operated in several control modes including:

- tele-operation, characterized by passive suspension compliance and manually commanded articulation;
- tele-managed, characterized by active suspension compliance, active self-articulation; and
- semi-autonomous, characterized by active suspension compliance, active self-articulation.

Capabilities associated with the various control modes in the illustrated embodiment are listed in Table 2.

TABLE 2

Capabilities Matrix

Control Class	Obstacle Capability
Tele-Operation	obstacle course, includes each of the following- articulation over 0.5–0.75 m step 0.5–0.75 m step drive off

TABLE 2-continued

Capabilities Matrix

Control Class	Obstacle Capability
	flat, benign terrain at 20 kph
	side slope stability
	max up-slope and down-slope climb
	high center recovery w/mast
	inverted operation
Tele-Managed	40 kph in tall grass
	flip-over recovery
	moderate terrain at 20 kph
	high wall stand-up & peek over
	GPS waypoint navigation (for total endurance testing on closed circuit courses
Semi-Autonomous	very rough terrain at 10 kph
	silent operations in very rough terrain at 6 kph
	canonical trench crossing (quasi-static)
	canonical wall crossing (quasi-static)
	1 meter step climb (quasi-static)
	active ground pressure control
	walking in very rough terrain
	transition to and from water
	Semi-Autonomous, Performance Envelop Expansion:
	Collaborative (using test mule as surrogate) obstacle crossing assistance
	Chimney-climb demo

In the illustrated embodiment, tele-operation and tele-management are performed through an Operator Control Unit ("OCU", not shown). The OCU is an extremely lightweight, man portable, hand-held and wearable unit remote from the UGV **100** (and out of harm's way), connected via military RF command link. It includes tele-operational capability as well as data display, storage and dissemination. A secondary fiber optic link can be used when RF signals are undesirable. The general microprocessor-based system has easily expandable I/O capabilities and substantial memory/processing power, providing much more flexibility and extensibility in the design. Exemplary OCUs with which this aspect of the invention can be implemented include, but are not limited to, FBI-Bot, AST, RATLER, DIXIE, SARGE, and TMSS.

The OCU of the illustrated embodiment also encompasses standard interfaces for versatility and future expandability; conforms with military specifications regarding temperature, humidity, shock, and vibration; allows operator to independently tele-operate single or multiple UGVs; uses standard military symbology to display location, movement, and status of friendly, hostile, and unknown units; represents terrain maps and nuclear, biological and chemical ("NBC") assessments using military grid reference system; and can provide auditory feedback for system status or relaying information from acoustic sensors onboard. The OCU provides real-time vehicle control capabilities as well as situational awareness displays for the forward element. The display can be wrist-mounted, head-mounted, or integral to the computing unit.

More particularly, in the illustrated embodiment, a map display (not shown) is updated in real-time with data from one or more UGVs **100**. Standard military symbology, such as is detailed in MIL-STD-2525B, displays the location, movement and status of friendly, hostile and unknown units. Vehicle status is displayed continually beside the unit icons and optionally with popup display of more detailed status information. Sensory data from the NBC detector and other sensory payloads are overlaid on the map display. Laser range finder and optical sensor gaze direction are represented on the display as a line radiating from the UGV icon. The terrain maps and NBC assessments are represented using the military grid reference system. Auditory feedback can be provided for system status or relaying information from acoustic sensors onboard the UGV.

Tele-operation of a single UGV **100** can be done with a first-person perspective view through use of real-time video and pointing device to control vehicle course and speed. Tele-management of single or multiple UGVs **100** can be accomplished via manipulating the corresponding UGV icons on the map to set destination objectives and paths. The real time video display can optionally be zoomed to fill the display with overlaid vehicle status appearing in a head-up display. The real-time video display also can be used during reconnaissance to show the live video view from the UGV **100** as if through binoculars. Multiple UGVs **100** can be controlled via mission orders issued by manipulating the UGV fleet icons on the map display or by issuing high-level commands, such as to surround a particular objective or to avoid a particular area while moving autonomously.

Note, however, that tele-operation and tele-management of the invention is not so limited. Various alternatives for remote operation and management of the UGV **100** are illustrated in FIG. **9**. For instance, control in these embodiments may be exercise from aboard an airborne command center **905**, at a forward observation post **910**, at a rear-echelon command and control center **920**, or at a central processing facility **930** over communications links **935***a*–**935***d*. The forward observation post **910**, rear-echelon command and control center **920**, and the central processing facility **930** may be airborne, ground-based (as shown) or marine. The communications links **935***a*–**935***d* may be direct, line of sight communications or relayed by satellite (not shown).

The invention admits wide variation. Consider the embodiment of FIG. **10**A–FIG. **10**B. In FIG. **10**A–FIG. **10**B, a UAV **1000** is implemented with a lighter-than-air vehicle, e.g., a balloon **1005** fitted with a sensor platform **1010**. The UAV **1000** can be stowed, as shown in FIG. **10**B, in the same manner as the UAV **120** in FIG. **3**B. The balloon **1005** is filled from a source of pressurized gas (not shown), and the latches **310** released. As the balloon **1005** rises, indicated by the arrow **1015** in FIG. **10**A, the UAV **1000** lifts from the recess **300**, thereby lifting the sensor platform **1010**. Once the sensing is complete, the UAV **1000** can be winched back to the recess **300** by the tether management system **200**, shown in FIG. **2**, and secured by the latches **310**. The balloon **1005** can then be deflated and the UAV **1000** stowed away. Alternatively, the tether **130** the deployment can terminating by severing or releasing the tether **130**, and the UAV **1000** permitted to float away. Note that, in this latter variation, the sensors aboard the sensing platform **1010** will preferably be inexpensive, as they may not be recoverable. It may also be desirable provide for the tether **130** to be detachable from the UGV **100** and/or the UAV **1000** and/or to be readily replaceable. Alternatively, the UAV **1000** can be retrieved, the sensor platform **1010** (or just the sensors mounted thereon) retained, the balloon **1005** (or the rest of the UAV **1000**) severed and allowed to float away.

Thus, the particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

What is claimed:

1. A virtual sensor mast for a ground vehicle, comprising:
an unmanned airborne vehicle capable of lifting itself from the ground vehicle upon deployment therefrom;
a sensor suite mounted to the unmanned airborne vehicle; and
a tether between the unmanned airborne vehicle and the ground vehicle over which the sensor suite is capable of communicating sensed data upon deployment.

2. The virtual sensor mast of claim **1**, wherein the unmanned airborne vehicle comprises a ducted fan.

3. The virtual sensor mast of claim **2**, wherein the ducted fan further comprises a plurality of ducted fans.

4. The virtual sensor mast of claim **1**, wherein the unmanned airborne vehicle comprises a lighter-than-air vehicle.

5. The virtual sensor mast of claim **4**, wherein the lighter-than-air vehicle comprises:
an inflatable balloon; and
a sensor platform affixed to the inflatable balloon and to which the sensor suite is mounted and the tether is affixed.

6. The virtual sensor mast of claim **1**, wherein the sensor suite includes at least one of:
an acoustic sensor;
an optical sensor;
a television camera;
a nuclear, biological and chemical detector;
an infrared sensor; and
a Global Positioning System sensor.

7. The virtual sensor mast of claim **1**, wherein the sensor suite comprises a plurality of sensors.

8. The virtual sensor mast of claim **1**, wherein the tether comprises at least one of:
an optical fiber:
a power lead;
a twisted wire pair; and
a coaxial cable.

9. The virtual sensor mast of claim **1**, wherein the tether is capable of transmitting power to the unmanned airborne vehicle.

10. The virtual sensor mast of claim **1**, further comprising a tether management system.

11. A ground vehicle, comprising:
a chassis;
a virtual sensor mast, including:
an unmanned airborne vehicle capable of lifting itself from the chassis upon deployment therefrom;
a sensor suite mounted to the unmanned airborne vehicle;
a tether between the unmanned airborne vehicle and the chassis over which the sensor suite is capable of communicating sensed data upon deployment
a processing system for controlling the operation of the ground vehicle, including the virtual sensor mast.

12. The virtual sensor mast of claim **11**, wherein the unmanned airborne vehicle a comprises a ducted fan.

13. The virtual sensor mast of claim **12**, wherein the ducted fan further comprises a plurality of ducted fans.

14. The virtual sensor mast of claim **11**, wherein the unmanned airborne vehicle comprises a lighter-than-air vehicle.

15. The virtual sensor mast of claim **14**, wherein the lighter-than-a vehicle comprises:
an inflatable balloon; and
a sensor platform affixed to the inflatable balloon and to which the sensor suite is mounted and the tether is affixed.

16. The virtual sensor mast of claim **11**, wherein the sensor suite includes at least one of:
an acoustic sensor;
an optical sensor;
a television camera;
a nuclear, biological and chemical detector;
an infrared sensor; and
a Global Positioning System sensor.

17. The virtual sensor mast of claim **11**, wherein the sensor suite comprises a plurality of sensors.

18. The virtual sensor mast of claim **11**, wherein the tether comprises at least one of:
an optical fiber;
a power lead;
a twisted wire pair; and
a coaxial cable.

19. The virtual sensor mast of claim **11**, wherein the tether is capable of transmitting power to the unmanned airborne vehicle.

20. The virtual sensor mast of claim **11**, further comprising a tether management system.

21. The ground vehicle of claim **11**, wherein the processing system is capable of processing data sensed by the sensor suite.

22. The ground vehicle of claim **21**, wherein the processing system is positioned within the chassis.

23. The ground vehicle of claim **11**, further comprising a receiver capable of receiving remotely generated command and control instructions for control of the ground vehicle.

24. The ground vehicle of claim **11**, further comprising a transmitter capable of transmitting data from the sensor suite to a remote location.

25. The ground vehicle of claim **11**, further comprising means for stowing the unmanned airborne vehicle.

26. The ground vehicle of claim **25**, wherein the stowing means comprises a recess in the chassis into which the unmanned airborne vehicle may be retrieved.

27. The ground vehicle of claim **25**, wherein the stowing means comprises a basket mounted on the chassis into which the unmanned airborne vehicle may be retrieved.

28. The ground vehicle of claim **11**, further comprising a tether management system housed in the chassis.

29. A vehicle, comprising:
a chassis;
a receiver mounted on the chassis; and
an unmanned airborne vehicle tethered to the chassis, the unmanned airborne vehicle housing at least one sensor and capable of transmitting sensed data to the receiver.

30. The virtual sensor mast of claim **29**, wherein the unmanned airborne vehicle comprises a ducted fans.

31. The virtual sensor mast of claim **30**, wherein the ducted fan further comprises a plurality of ducted fans.

32. The virtual sensor mast of claim **29**, wherein the unmanned airborne vehicle comprises a lighter-than-air vehicle.

33. The virtual sensor mast of claim **32**, wherein the lighter-than-air vehicle comprises:
an inflatable balloon; and
a sensor platform affixed to the inflatable balloon and to which the sensor suite is mounted and the tether is affixed.

34. The virtual sensor mast of claim **29**, wherein the sensor suite includes at least one of:

an acoustic sensor;
an optical sensor;
a television camera;
a nuclear, biological and chemical detector;
an infrared sensor; and
a Global Positioning System sensor.

35. The virtual sensor mast of claim **29**, wherein the sensor suite comprises a plurality of sensors.

36. The virtual sensor mast of claim **29**, wherein the tether comprises at least one of:

an optical fiber;
a power lead;
a twisted wire pair; and
a coaxial cable.

37. The virtual sensor mast of claim **29**, wherein the tether is capable of transmitting power to the unmanned airborne vehicle.

38. The virtual sensor mast of claim **29**, further comprising a tether management system.

39. A method far use in operating a ground vehicle, comprising:

elevating a tethered unmanned airborne vehicle from the ground vehicle to a predetermined height;
sensing environmental conditions surrounding the ground vehicle from the unmanned airborne vehicle;
transmitting the sensed data from the unmanned airborne vehicle to the around vehicle; and
terminating the deployment.

40. The method of claim **39**, wherein elevating the unmanned airborne vehicle includes activating a ducted fan.

41. The method of claim **39**, wherein elevating the unmanned airborne vehicles includes activating a lighter-than-air vehicle.

42. The method of claim **39**, wherein sensing the environmental conditions includes sensing the environmental conditions with at least one of:

an acoustic sensor;
an optical sensor;
a television camera
a nuclear, biological and chemical detector;
an infrared sensor, and
a Global Positioning System sensor.

43. The method of claim **39**, wherein terminating the deployment includes retrieving the unmanned airborne vehicle.

44. The method of claim **43**, wherein retrieving the unmanned airborne vehicle includes retrieving the unmanned airborne vehicle into a recess.

45. The method of claim **43**, wherein retrieving the unmanned airborne vehicle includes retrieving the unmanned airborne vehicle into a basket.

46. The method of claim **39**, wherein terminating the deployment includes releasing the unmanned airborne vehicle.

47. The method of claim **39**, further comprising transmitting sensed data to a remote location.

48. The method of claim **39**, further comprising remotely controlling the operation of the ground vehicle.

* * * * *