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Mohamadi

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(54) **MULTI-STAGE DETECTION OF BURIED IEDS**

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G01S 17/02 (2006.01)
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F41H 11/136 (2011.01)
G01S 13/88 (2006.01)
B64C 39/02 (2006.01)
G01S 13/02 (2006.01)

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CPC ***G01S 17/89*** (2013.01); ***B64C 39/024*** (2013.01); ***F41H 11/136*** (2013.01); ***G01S 13/867*** (2013.01); ***G01S 13/885*** (2013.01); ***G01S 13/89*** (2013.01); ***G01S 17/023*** (2013.01); *B64C 2201/027* (2013.01); *B64C 2201/108* (2013.01); *B64C 2201/123* (2013.01); *B64C 2201/127* (2013.01); *B64C 2201/146* (2013.01); *G01S 13/0209* (2013.01)

(58) **Field of Classification Search**

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USPC 342/22, 73, 90, 96
See application file for complete search history.

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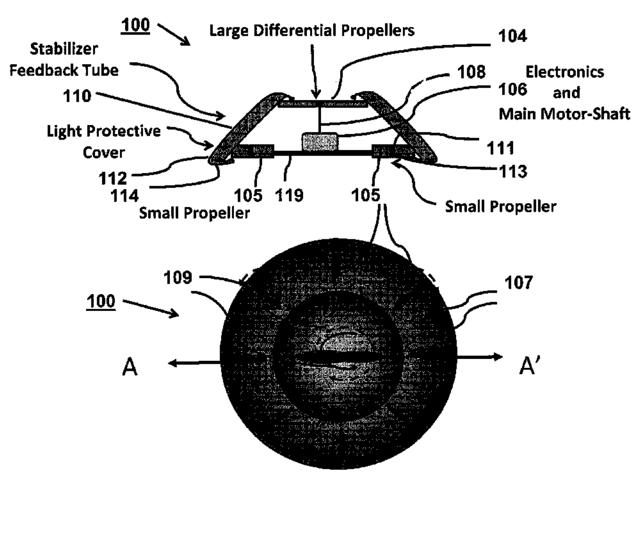
(57) **ABSTRACT**

A surveillance system includes a multi-propeller aircraft having a main propeller and a plurality of wing unit propellers; a housing that houses the main propeller and the wing unit propellers; an optical video camera; an ultra-wideband (UWB) radar imaging system; a control system for controlling flight of the multi-propeller aircraft from a remote location; and a telemetry system for providing information from the optical camera and the ultra-wideband (UWB) radar imaging system to a remote location.

9 Claims, 9 Drawing Sheets



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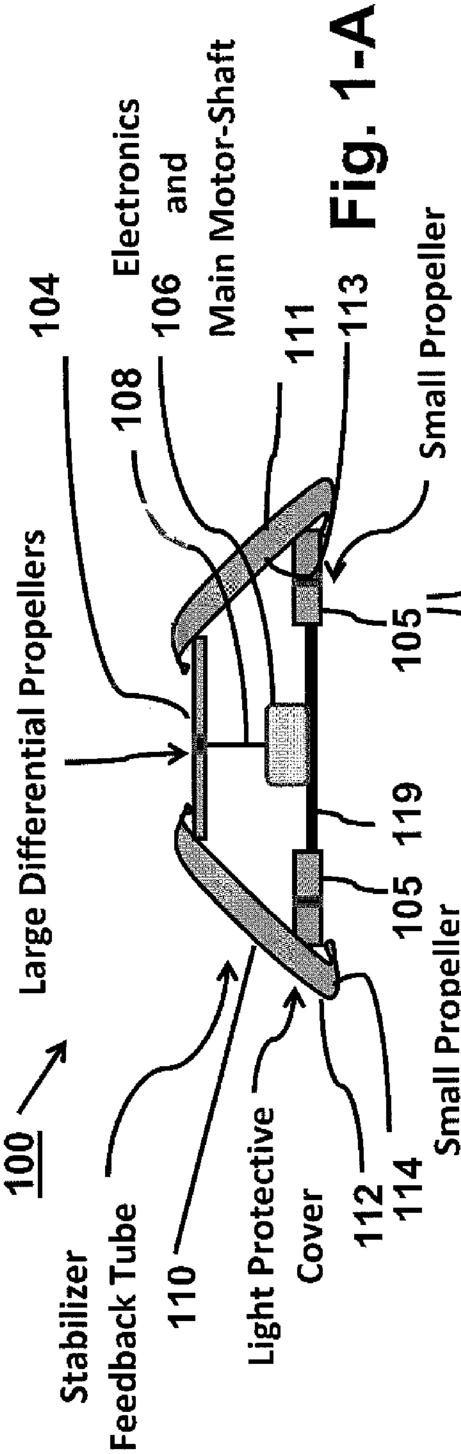

100
Large Differential Propellers
104
108
106
Electronics
and
Main Motor-Shaft
111
113
Small Propeller
105
119
105
Small Propeller
Stabilizer
Feedback Tube
110
Light Protective
Cover
112
114

Fig. 1-A

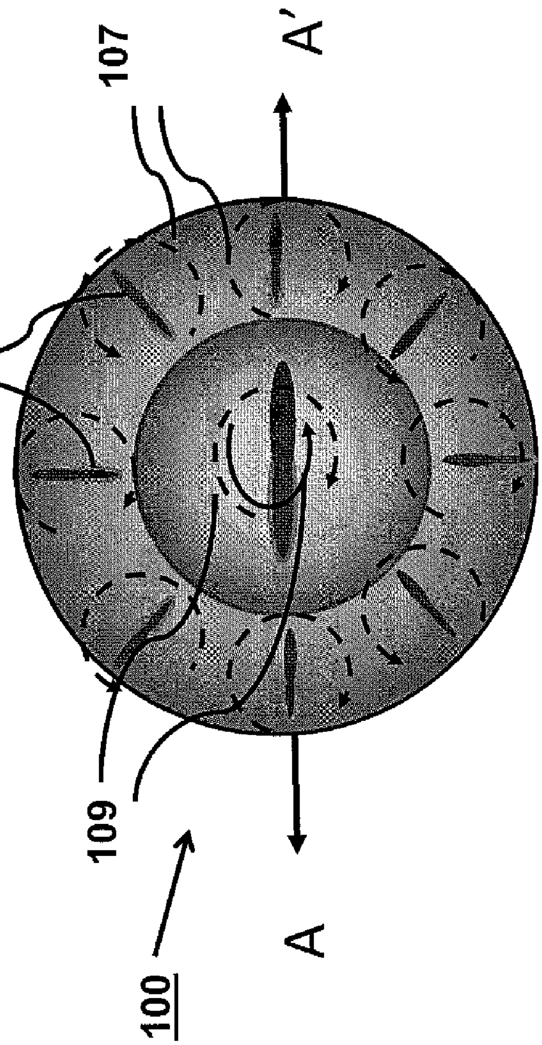

100
A
109
105
107
A'

Fig. 1-B

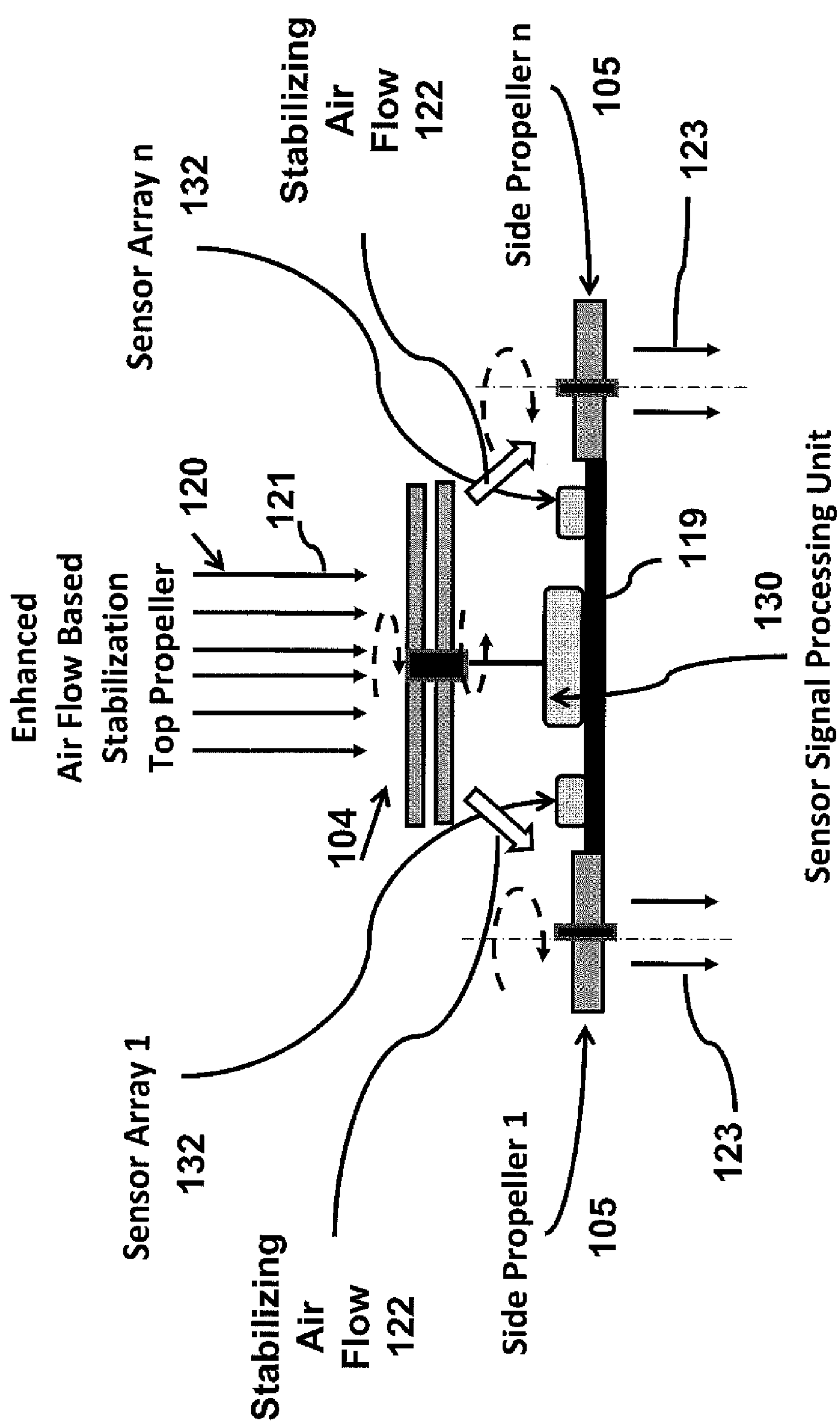

Enhanced
Air Flow Based
Stabilization
Top Propeller
120
121
104
Sensor Array n
132
Stabilizing
Air
Flow
122
Side Propeller n
105
123
119
130
Sensor Signal Processing Unit
Sensor Array 1
132
Stabilizing
Air
Flow
122
Side Propeller 1
105
123

Fig. 2

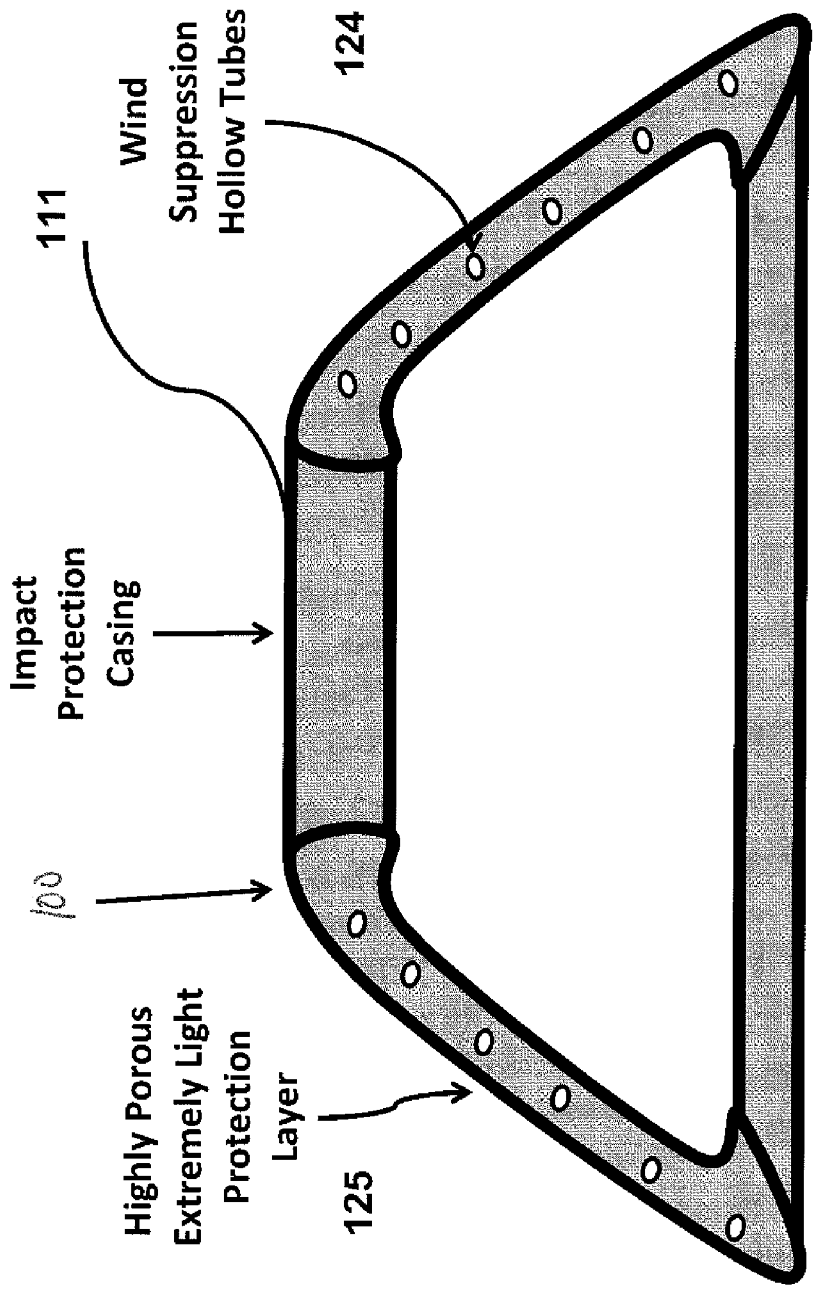

111
Wind Suppression Hollow Tubes
124
Impact Protection Casing
100
Highly Porous Extremely Light Protection Layer
125

Fig. 3

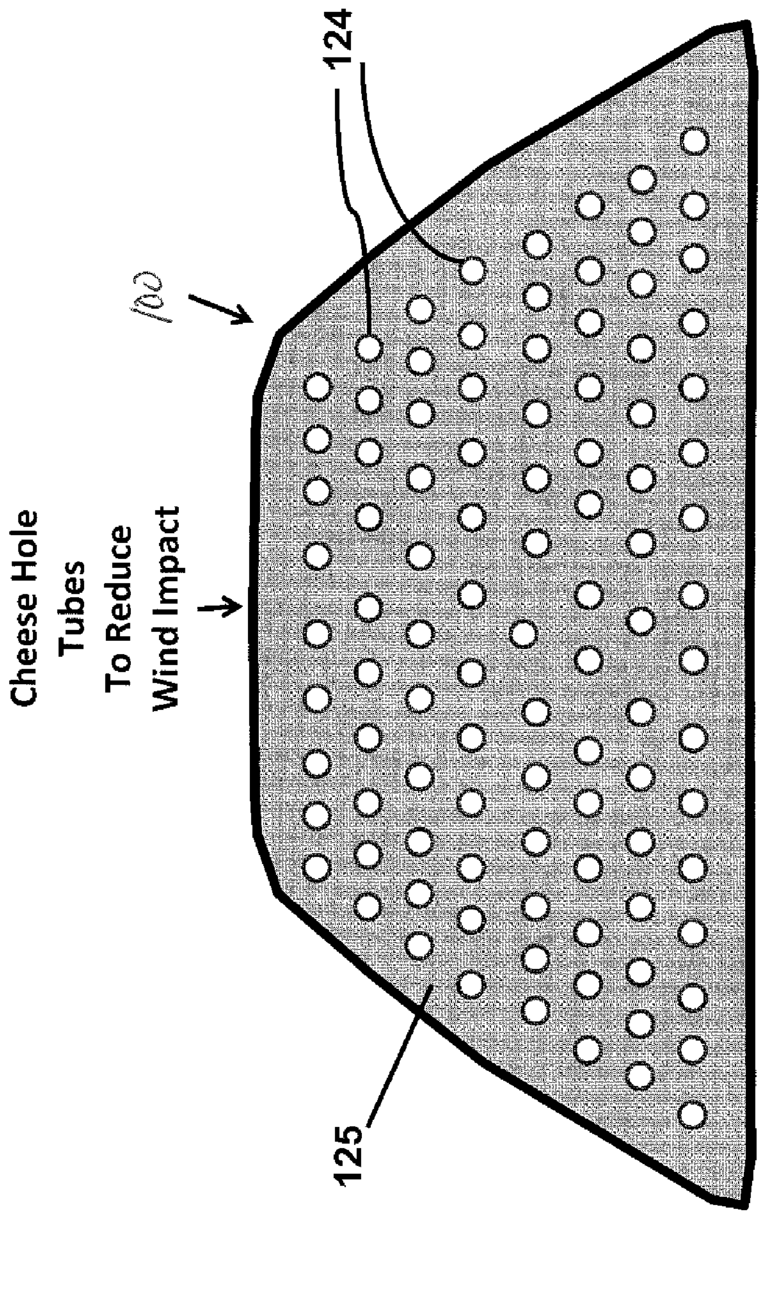


Fig. 4

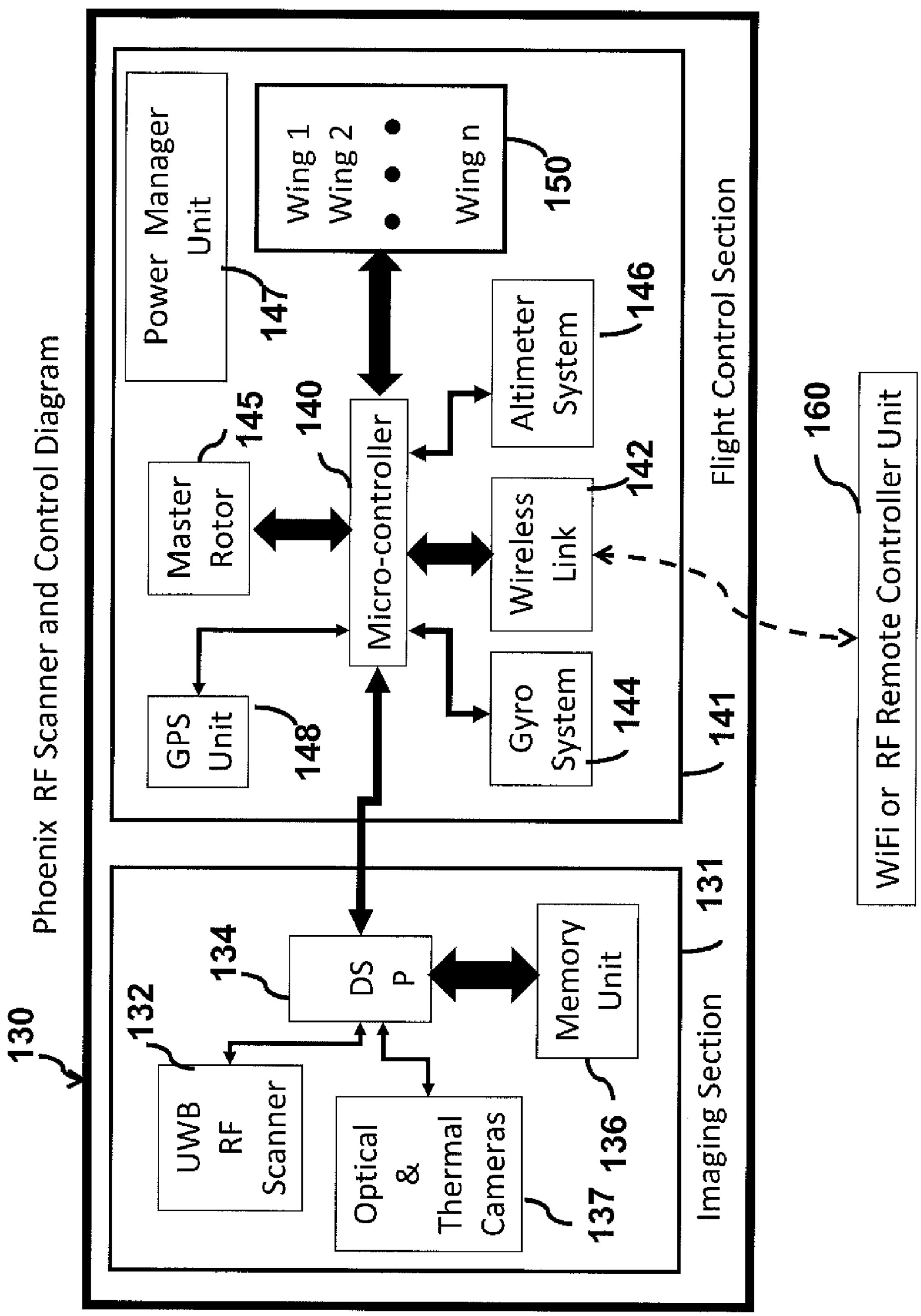

Phoenix RF Scanner and Control Diagram
130
Imaging Section
131
UWB RF Scanner
132
DS P
134
Memory Unit
136
Optical & Thermal Cameras
137
Flight Control Section
141
GPS Unit
148
Master Rotor
145
Power Manager Unit
147
Micro-controller
140
Wing 1
Wing 2
Wing n
150
Gyro System
144
Wireless Link
142
Altimeter System
146
WiFi or RF Remote Controller Unit
160

Fig. 5

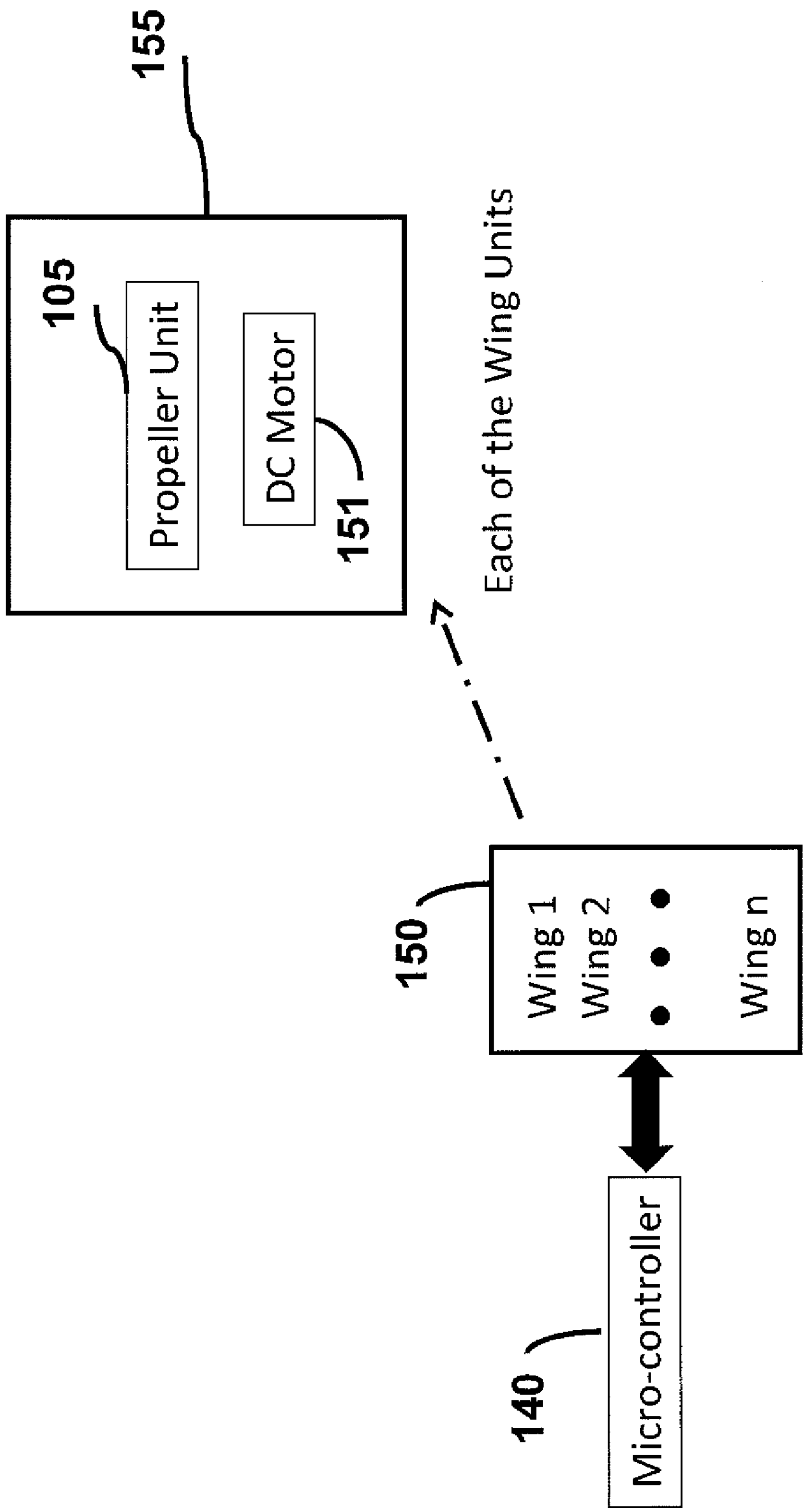

155
105
Propeller Unit
DC Motor
151
Each of the Wing Units
150
Wing 1
Wing 2
Wing n
140
Micro-controller

Fig. 6

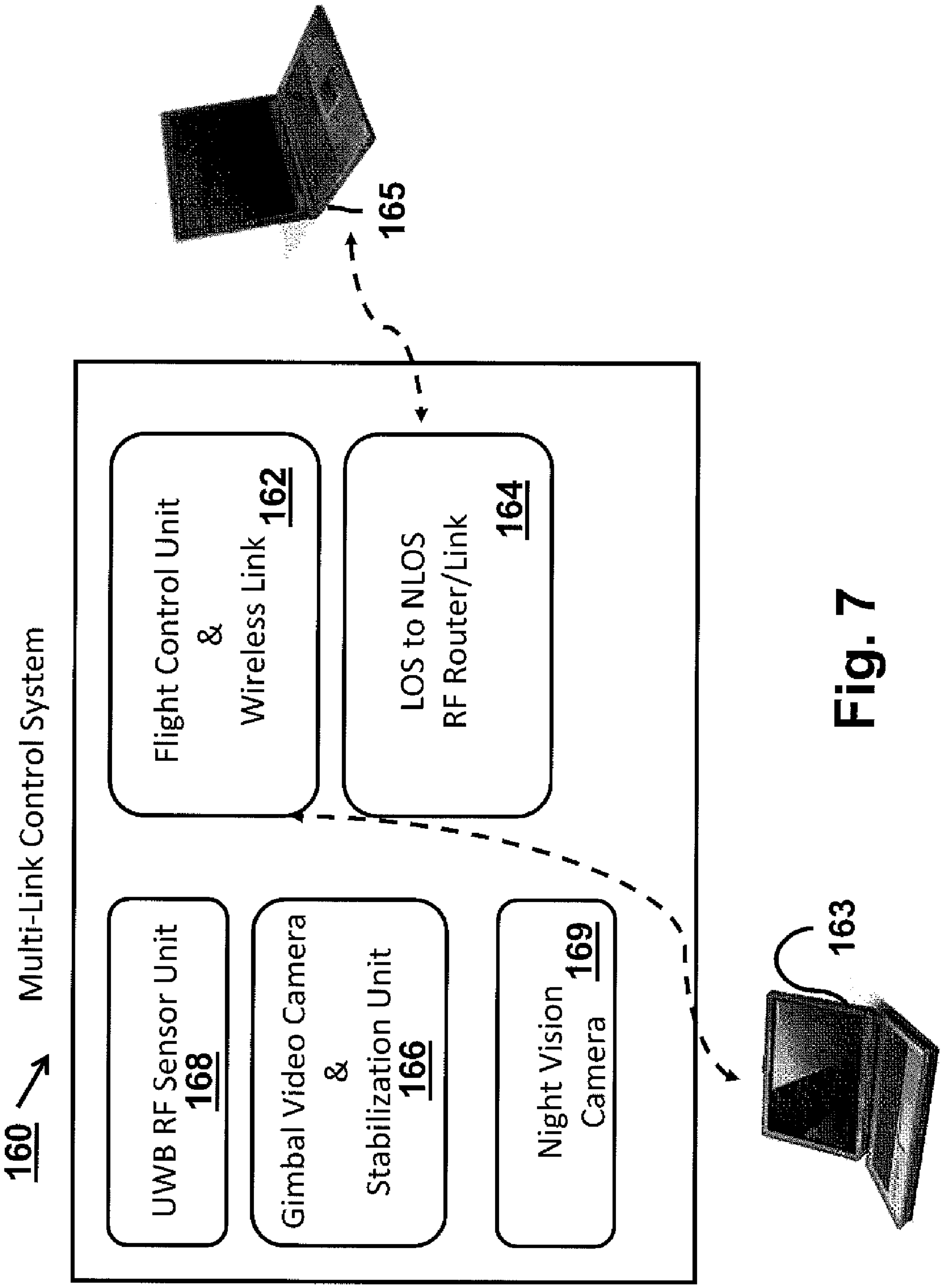

160
Multi-Link Control System
UWB RF Sensor Unit 168
Gimbal Video Camera & Stabilization Unit 166
Night Vision Camera 169
Flight Control Unit & Wireless Link 162
LOS to NLOS RF Router/Link 164
163
165

Fig. 7

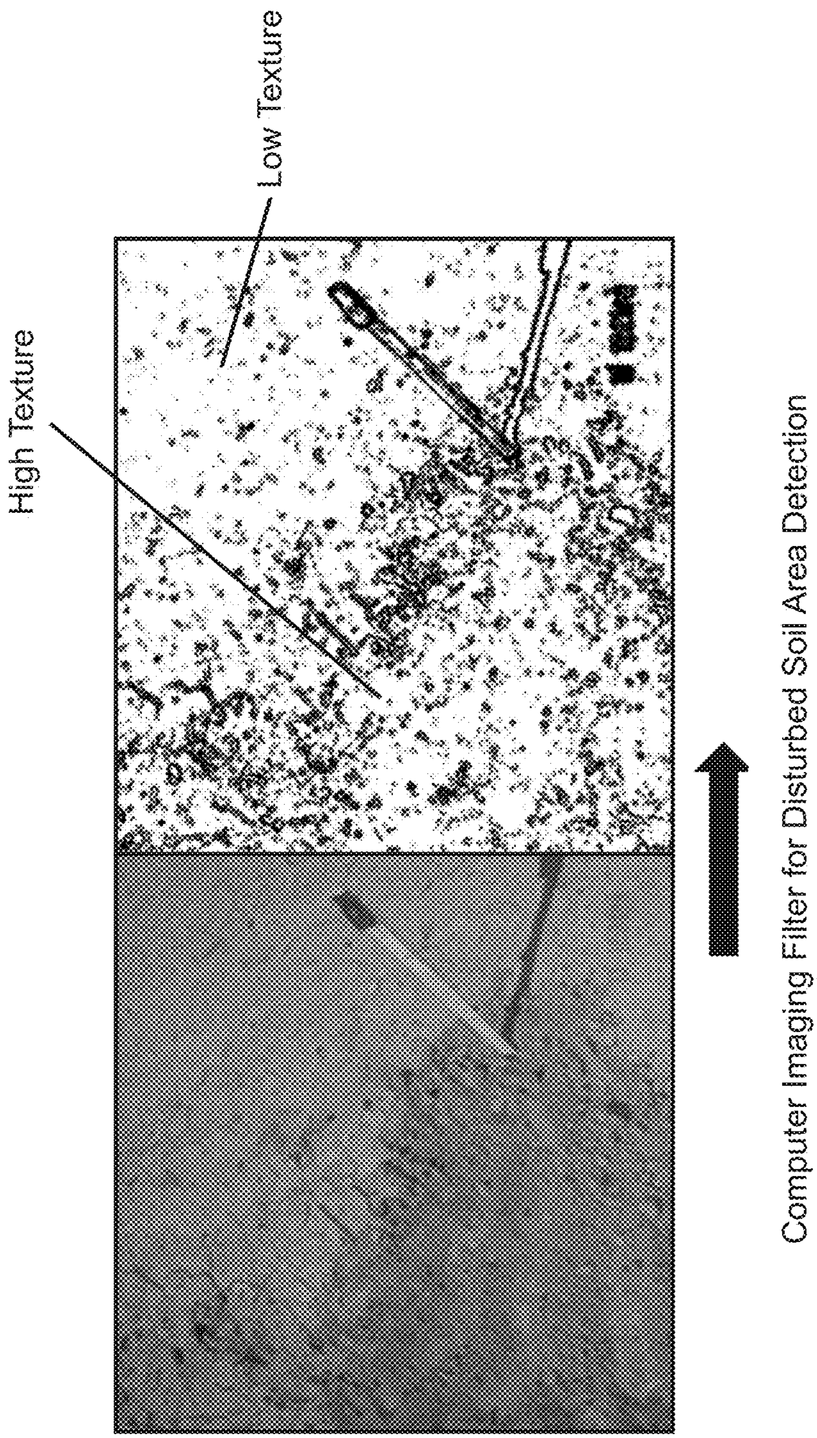
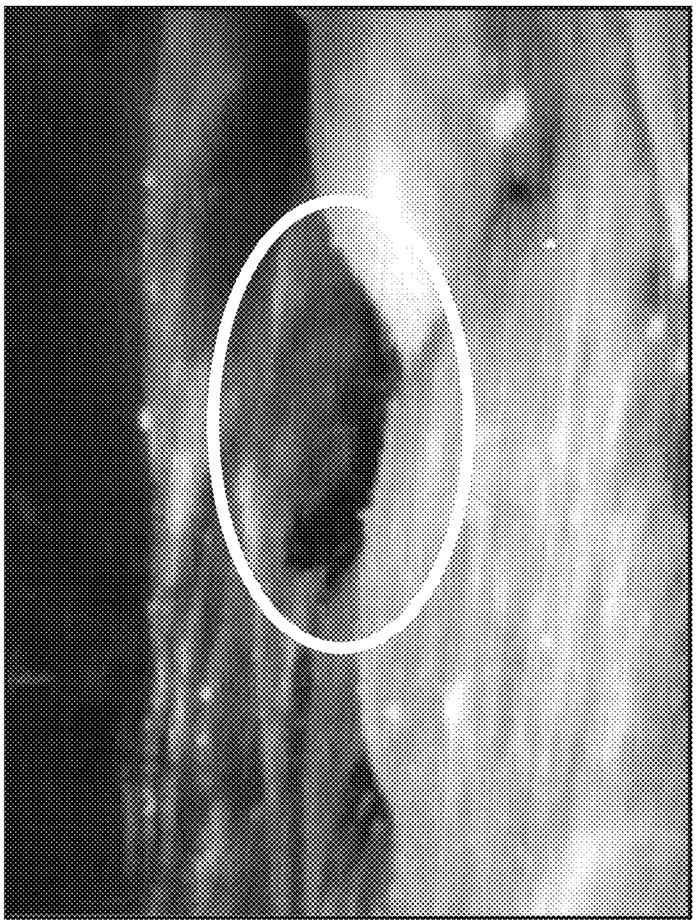

High Texture
Low Texture
Computer Imaging Filter for Disturbed Soil Area Detection

FIG. 8



Thermal Image of Disturbed Soil

FIG. 9

MULTI-STAGE DETECTION OF BURIED IEDS

This application claims the benefit of U.S. Provisional Application No. 61/435,123, filed Jan. 21, 2011, which is incorporated by reference. In addition, this application is related to the following co-pending application, which is incorporated by reference: U.S. patent application No. 13/037,804, filed Mar. 1, 2011.

BACKGROUND

The present disclosure generally relates to radio frequency (RF) detection and ranging (RADAR) and, more particularly, to providing surveillance information to an operator of buried ordnance or other types of improvised explosive devices (IEDs).

While massive effort has been exerted for the detection of IEDs, there is no single system that is capable of clearly identifying them both in-road and off-road. Accordingly, there is a need in the art for an ED detection system that includes an integrated set of sensors.

SUMMARY

According to one embodiment, a system includes: a multi-propeller aircraft having a main propeller and a plurality of wing unit propellers; a housing that houses the main propeller and the wing unit propellers; an ultra-wideband (UWB) radar imaging system housed in the housing; a control system, housed in the housing, for controlling flight of the multi-propeller aircraft from a remote location; and a telemetry system, housed in the housing, for providing information from the ultra-wideband (UWB) radar imaging system to the remote location.

According to another embodiment, a method includes: remotely controlling flight of an aircraft using a main propeller and a plurality of wing unit propellers for lift and propulsion; operating an ultra-wideband (UWB) radar imaging system from the aircraft; and transmitting information from the UWB radar imaging system to a display at a location remote from the aircraft.

According to a further embodiment, an unmanned aerial vehicle includes: a ground plate; a plurality of wing propeller units attached to the ground plate; a housing attached to the ground plate; a main propeller unit connected, directly or indirectly, to the ground plate and disposed to provide a portion of airflow to the wing propeller units; and a control system in communication with the main propeller unit and the wing propeller units and providing flight control by adjustment of the speed and thrust from all of the propeller units concurrently.

The scope of the invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a cross sectional diagram, taken along line A-A' in FIG. **1**B, of a standoff surveillance system apparatus in accordance with one embodiment;

FIG. **1**B is a plan view diagram of a standoff surveillance system apparatus in accordance with one embodiment;

FIG. **2** is a side view diagram of system components of a standoff surveillance system apparatus in accordance with an embodiment;

FIG. **3** is a side sectional view toward an interior of a housing for a standoff surveillance system apparatus in accordance with an embodiment;

FIG. **4** is a side view of an exterior of a housing for a standoff surveillance system apparatus in accordance with an embodiment;

FIG. **5** is a system diagram illustrating one example of a system architecture for a standoff surveillance system in accordance with an embodiment;

FIG. **6** is a system diagram illustrating the wing propeller units shown in FIG. **5** in more detail, in accordance with one embodiment; and

FIG. **7** is a system diagram illustrating one example of a system architecture for a system interface and remote control for a standoff surveillance system in accordance with one embodiment.

FIG. **8***a* is an illustration of a disturbed ground patch and adjacent undisturbed ground.

FIG. **8***b* illustrates the results of a texture filtering image processing algorithm on the image of FIG. **8***a*.

FIG. **9** illustrates a thermal image of disturbed soil.

Embodiments and their advantages are best understood by referring to the detailed description that follows. Like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

To provide an integrated sensor system, the present invention exploits the multi-propeller remote-controlled aircraft disclosed in U.S. application No. 13/037,804 (the 804 application). In one or more embodiments, the aircraft disclosed herein may include multiple sensors, such as a combination of a 5 Giga Hertz (GHz) ultra-wideband (UWB) radar imaging system, a very high frequency, e.g., 60 GHz ultra-wideband radar imaging system, and an optical imaging system. The optical imaging system may include a visual light video camera as wells as an infrared imaging system. The radiated power UWB radar imaging system in one embodiment may be less than 100 microwatts (μW). Advantageously, the multi-sensor aircraft may be miniaturized to have within a 1 foot to 2 foot radius and weigh less than 3 lbs. (excluding the electronics).

In one or more embodiments, the multi-propeller system disclosed herein may accomplish easy, noiseless take-off and landing of its embedded ultra-wideband radar imaging system for survey of suspected TED locations. FIG. **1** illustrates an example integrated-multi-sensor unmanned aerial vehicle (UAV) **100**. UAV **100** include a housing **112** for enclosing electronics **106** corresponding to an RF/optical imaging and flight control system **130** (see FIG. **5**) and for enclosing other system components such as a pair of main propellers **104** (for illustration clarity, only a single main propeller is shown but it will be appreciated that a pair of counter-rotating propellers **104** are required in the absence of a tail rotor), wing unit propellers **105**, main motor shaft **108**, and ground plate **119**. In one implementation, the wing unit propellers **105** may be comprise pairs of coaxial propellers with counter spinning capability to double the air flow and neutralize the torque. In another implementation, every other wing unit propeller **105** may be spinning opposite to the previous one in sequence around the periphery of ground plate **119** to neutralize the torque. In a third implementation, the main propeller **104** may be balanced by the wing unit propellers **105**. Housing **112** may include a light weight protective cover **125** (see FIGS. **3** and **4**) encasing its outer surface **111**. The surface of the cover **125** may be tiled with solar cells, which may be connected to an internal rechargeable battery for prolonged operations. The outer edge of the ground plate **119** may be buffered with a soft plastic bumper **114**, which may be attached to housing **112** for smooth landing of the aircraft **100**. Housing **112** may also have an inner surface **113** (FIG. **1**) which may be shaped to direct an airflow **122** (see FIG. **2**) from the main propeller **104** into wing unit propellers **105**. Housing **112** may also include one or more stabilizer feedback tubes **110** for directing airflow between the main propeller **104** and the wing unit propellers **105**. For example, the air flow may be through the main large propeller **104** and a portion of outflow air may be fed back to the smaller propellers **105** through a narrow tube **110** for stability. Direction of rotation (indicated by arrows **107** and **109**) and rate of rotation of each propeller may be controlled for stable take-off and landing. As indicated by arrows **107** and **109** some of the propellers may be counter rotating with respect to each other for control of the overall net torque and rotational inertia for all of the propellers. In other embodiments, UAV **100** includes only a plurality of wing unit propellers **105** such that main propellers **104** are omitted.

The wing unit propellers **105** are circularly arranged with regard to UAV **100** such that UAV **100** is symmetric. In other words, if there are just four wing unit propellers, each wing unit propeller would be separated from adjacent wing unit propellers by ninety degrees. The result is that UAV **100** is very compact, having a diameter of approximately 1.5 feet to 3.0feet, more preferably around 2 feet in diameter. Such sizes provide robust wind resistance yet are relatively inexpensive while still maintaining unique maneuverability. For example, UAV **100** may readily travel from 0 to 10 meters per second at a height of 1 to 5 feet as it scans for improvised explosive devices (IEDs). Given the relatively small size of UAV **100**, such scanning is relatively stealthy. In contrast, a fixed-wing UAV would have to maintain much greater airspeeds, which limits the scanning resolution. Moreover, fixed wing UAVs cannot scan close to the ground in cluttered urban environments. Larger hovering aircraft would also be problematic in cluttered environments. In contrast, UAV **100** is readily deployed in such environments.

FIG. **2** is a side view diagram of system components that may be enclosed in a housing **112** of UAV **100**. FIG. **2** shows a general layout of components on a supporting ground plate **119**, to which the components may be attached and to which the housing **112** may also be connected, either directly or indirectly, for support of the housing **112**. In an alternative embodiment, the housing **112** may provide support for components that are attached to it and held, for example, by ground plate **119**. As seen in FIG. **2**, the supported components may include sensor arrays **132** (see also FIG. **5**) which may include, for example, UWB radar scanners, video and audio inputs such as cameras and microphones, night vision cameras, global positioning system (GPS) units, altimeters, and gyro systems. The supported components may include sensing, flight control, and telemetry system **130** (also referred to as "sensor signal processing unit" or "RF scanner and control system" as in FIG. **5**). FIG. **2** also shows more clearly airflow **120** through the propellers **104** and **105**, comprising entry airflow **121**, stabilizing airflows **122**, and exit airflows **123**. As may be seen from FIG. **2**, most of the components are mounted near the ground plate, so that the center of gravity is very close to the ground plate, which is low in the UAV **100** for stability.

FIG. **3** shows an interior of UAV **100** and FIG. **4** shows an exterior of a UAV **100**. Wind suppression hollow tubes **124** open through the protective cover **125**. Protective cover **125** may provide impact protection for UAV **100** and may be rendered porous—for example, with regard to cross winds—and lighter in weight by the openings of hollow tubes **124**. In one implementation the tubes **124** may be formed to collect the wind (large area inlet) and spray jet (smaller cross section outlet) back the air to resist the wind. The number of tubes **124** may be very large, while the weight of each tube may be ultra light. In another implementation, the tubes **124** may form a large honeycomb type structure that passes the air through and provides almost no resisting surface to the wind, while mechanically supporting the UAV **100** against shock.

FIG. **5** illustrates one example of a system architecture for sensing, flight control, and telemetry system **130**. Sensing, flight control, and telemetry system **130** may include an imaging section **131** and a flight control section **141**, which may communicate wirelessly via a remote controller unit included in a control system **160** (see also FIG. **7**). Wireless control system **160** may conform, for example, to any of the open standards or may be a proprietary control system. Wireless network connectivity may be provided by a wireless control system **160**.

Imaging section **131** may include one or more UWB RF scanners (e.g., sensor array **132**) such as, for example, the 5 GHz or 60 GHz systems referenced above. In addition, imaging section **131** includes an optical video camera **137**. The UWB RF scanner (sensor array unit **132**) and camera **137** may be connected to a digital signal processing (DSP) unit **134**, which may access a memory unit **136** comprising, for example, a random access memory (RAM). The DSP unit **134** may communicate, as shown in FIG. **5**, with flight control section **141**. The UWB RF scanners may scan the ground over a field of view that ranges from 20 to 150 degrees.

Flight control section **141** may include a micro-controller **140**. Micro-controller **140** may integrate all sensory and control inputs from the components of flight control section **141** and may provide control and telemetry outputs for UAV **100**. As shown in FIG. **5**, micro-controller **140** may receive inputs from wireless link **142**, which may provide operator control inputs from an operator at a remote location using, for example, a wifi or RF remote controller unit of wireless control system **160**. Micro-controller **140** may receive additional control and stabilizing inputs, for example, from gyro system **144** and altimeter system **146**. Micro-controller **140** may receive position or location data from GPS system **148**. For example, inputs from GPS system **148** may enable UAV **100** to report its position via telemetry and to be monitored over Google® maps, for example, using GPS.

Micro-controller **140** may provide control outputs and receive feedback inputs from master rotor unit **145** and wing propeller units **150**. Master rotor unit **145** may include the main propeller(s) **104**, a main motor and motor shaft **108**, and an electronic speed control (ESC) for driving the motor. Similarly, as shown in FIG. **6**, each wing propeller unit **155** of the plurality of wing propeller units **150** may include a wing unit propeller **105**, a DC motor **151** and an ESC (not shown) for driving the motor. Each wing propeller unit **155** may include a local controller and a micro-electro mechanical (MEM) based gyro or accelerometer (not shown).

Flight control section **141** may also include a power manager unit **147** for providing and regulating electrical power to any of the systems of UAV **100**.

FIG. 7 illustrates one example of a multi-link wireless control system 160 for standoff surveillance system 100. Multi-link wireless control system 160 may include a system interface display (e.g., devices 163, 165) for providing surveillance information to a user from an RF imaging system or other surveillance systems (e.g., video, audio) on UAV 100. Control system 160 may provide a system interface for one or more operators using display and input devices 163 and 165 to communicate with and control UAV 100 at a location remote from UAV 100. The remote controller may be a laptop or hand-held system as illustrated by devices 163, 165 shown in FIG. 7, or a device that provides joy stick controls, for example, for the rate of rotation for each of propellers 104, 105. For example, flight control may be provided by adjustment of the speed and thrust from all of the propeller units concurrently under direction of micro-controller 140, which may interpret signals from the joysticks to co-ordinate the adjustments.

Multi-link wireless control system 160 may provide links, as shown, for a UWB radar RF sensor unit 168, gimbal video camera and stabilization unit 166, night vision camera 169, flight control unit 162, and line-of-sight (LOS) to non-line-of-sight (NLOS) router link 164. Each of these units may, for example, process telemetry data or interface control inputs to a corresponding unit on UAV 100. Interface display 163, for example, may provide first person view (FPV) control and direct visual flight control for UAV 100 as well as display telemetry data such as RF imaging from the UWB radar sensors on board the UAV 100. Interface display 165 may provide an LOS to NLOS router link for UAV 100.

The integrated RE and optical sensors in UAV 100 enable a multi-stage mode of operation. In an initial optical stage, the flying UAV 100 images the ground surface using its optical camera. The resulting video image may be analyzed within system 160 for the presence of disturbed ground as would be characteristic of buried IEDs. For example, edge detection and high pass image processing algorithms may be used to detect the presence of disturbed ground within the resulting video image. In a subsequent mode of operation, UAV 100 interrogates the identified disturbed ground patches with UWB radar to confirm or deny the presence of buried IEDs beneath the disturbed ground surface. It will be appreciated that UAV 100 may include an integrated infrared camera in addition to or in place of optical camera 137. The video analysis for disturbed ground may thus be conducted in both the visual and infrared spectrums.

FIG. 8*a* shows the difference between disturbed ground surface such as from the burying of an IED and undisturbed ground surface. Such a disturbed surface may be readily detected using an optical image processing algorithm such as a texture filtering algorithm as shown in FIG. 8*b*. The disturbed ground surface has a relatively high texture as compared to the low texture for the undisturbed ground surface. As discussed above, conventional edge detection and high pass image processing algorithms may also be used to detect the presence of disturbed ground.

Referring back to FIG. 5, the RF scanner 132 may be supplemented with a water-exciting microwave transmitter such as a 2.4 GHz transmitter. UAV 100 can thus advantageously hover at approximately 1 to 5 feet from a ground surface and excite the soil surface with the microwave transmitter. Disturbed ground has a different dewpoint and thus a correspondingly different thermal profile from undisturbed ground in response to such thermal excitation from the microwave transmitter. Camera 137 can thus include an infrared camera to detect the resulting disturbed ground thermal signature in conjunction with the microwave excitation. FIG. 9 illustrates an example thermal image of excited disturbed soil. The disturbed ground is readily thermally distinguished from the surrounding undisturbed soil.

Consider the advantages of UAV 100. It offers a user a coarse detection mode using optical analysis in either the visible or infrared spectrum while also offering a fine detection mode using UWB radar. Unlike conventional fixed wing or hovering aircraft, UAV 100 is relatively small, having a diameter of between 1.5 and 3 feet. Thus, UAV 100 is extremely maneuverable around cluttered terrain. Moreover, UAV 100 may be configured with conventional explosive discoloration agents that react with common explosive materials. In this fashion, UAV 100 could not only detect the presence of suspected IEDs but also authenticate such detections by subsequently spraying the disturbed ground location with the explosive discoloration agent.

Embodiments described herein illustrate but do not limit the disclosure. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the present disclosure. Accordingly, the scope of the disclosure is best defined only by the following claims.

I claim:

1. A system comprising:

a multi-propeller aircraft having a plurality of wing unit propellers for vertical takeoff and landing;

a housing that houses a main propeller and the wing unit propellers, the housing having a diameter of approximately 1.5 feet to 3 feet;

an ultra-wideband (UWB) radar imaging system housed in the housing;

an optical camera within the housing:

a control system, housed in the housing, for controlling flight of the multi-propeller aircraft from a remote location;

a microwave transmitter configured to heat water within or on one or more ground surfaces;

an infrared camera for detecting a heat signature of a ground surface in response to the heating from the microwave transmitter; and

a telemetry system, housed in the housing, for providing information from the ultra-wideband (UWB) radar imaging system and the optical camera to the remote location, wherein the system is configured to

first interrogate a ground surface with the optical camera to locate disturbed ground surfaces and with the microwave transmitter and the infrared camera to locate a disturbed ground surface by detecting a thermal profile of the disturbed ground in response to the heating from the microwave transmitter based on the disturbed ground having a different dewpoint and thus a correspondingly different thermal profile from undisturbed ground and

to subsequently interrogate the disturbed ground surface with the UWB radar imaging system, wherein the system is further configured to:

scan, from the aircraft, a general area of interest using a first UWB radar system operating at a first center frequency;

perform a coarse analysis using data provided by the first radar system to isolate a target of interest from clutter;

display imaging of the target of interest on a display at the remote location;

remotely direct the aircraft to scan the target of interest using a second ultra-wideband (UWB) radar system operating at a second center frequency that is higher than the first center frequency;

perform a fine analysis using narrow beam data provided by the second radar system; and

display imaging of the results of the fine analysis on the display at the remote location.

2. The system of clam **1**, wherein the multi-propeller aircraft further includes an explosive discoloration agent spray system to spray the interrogated disturbed ground surface with explosive discoloration agent to authenticate the presence of buried IEDs.

3. The system of claim **1**, further comprising:

a global positioning system (GPS) sensor integrated with the UWB radar sensor imaging for providing real-time feedback of information.

4. The system of claim **1**, wherein:

real-time feedback of information from the ultra-wideband (UWB) radar imaging system is available on a display for remote control operation of the aircraft.

5. A method comprising:

remotely controlling flight of an aircraft using a plurality of wing unit propellers for vertical take off and landing;

operating an optical video camera mounted on the aircraft to detect the presence of disturbed ground patches;

operating a microwave transmitter configured to heat water within or on one or more ground patches;

operating an infrared camera for detecting a heat signature of at least one of the ground patches in response to the heating from the microwave transmitter to locate a disturbed ground patch having a different dewpoint and thus a correspondingly different thermal profile from undisturbed ground in response to the heating from the microwave transmitter;

operating an ultra-wideband (UWB) radar imaging system from the aircraft to image the disturbed ground patches for the presence of buried improvised explosive devices (IEDs) from a height of approximately 1 to 5feet from the disturbed ground patches;

scanning, from the aircraft, a general area of interest using a first UWB radar system operating at a first center frequency;

performing a coarse analysis using data provided by the first radar system to isolate a target of interest from clutter;

transmitting information from the UWB radar imaging system to a display at a location remote from the aircraft;

displaying imaging of the target of interest on the display at the location remote from the aircraft;

remotely directing the aircraft to scan the target using a second ultra-wideband (UWB) radar system operating at a second center frequency that is higher than the first center frequency;

performing a fine analysis using narrow beam data provided by the second radar system; and

displaying imaging of the results of the fine analysis on the display at the location remote from the aircraft.

6. The method of claim **5**, further comprising:

spraying an explosive discoloration agent, that reacts with common explosive materials, on the interrogated disturbed ground surface to authenticate the presence of buried IEDs.

7. A method comprising:

remotely controlling flight of an aircraft using a plurality of wing unit propellers for vertical take off and landing;

operating an optical video camera mounted on the aircraft to detect the presence of disturbed ground patches;

operating an ultra-wideband (UWB) radar imaging system from the aircraft to image the disturbed ground patches for the presence of buried improvised explosive devices (IEDs) from a height of approximately 1to 5feet from the disturbed ground patches;

transmitting information from the UWB radar imaging system to a display at a location remote from the aircraft;

from the aircraft, exciting a disturbed surface of at least one of the disturbed ground patches with a microwave transmitter configured to heat water within the disturbed surface, wherein the optical video camera comprises an infrared camera configured to detect a heat signature of the excited disturbed surface having a different dewpoint and thus a correspondingly different heat signature from undisturbed ground in response to the heating from the microwave transmitter;

scanning, from the aircraft, a general area of interest using a first UWB radar system operating at a first center frequency;

performing a coarse analysis using data provided by the first radar system to isolate a target of interest from clutter;

displaying imaging of the target of interest on the display at the location remote from the aircraft;

remotely directing the aircraft to scan the target using a second ultra-wideband (UWB) radar system operating at a second center frequency that is higher than the first center frequency;

performing a fine analysis using narrow beam data provided by the second radar system; and

displaying imaging of the results of the fine analysis on the display at the location remote from the aircraft.

8. The method of claim **7**, wherein operating the optical video camera comprises performing an image processing texture filtering.

9. The method of claim **7**, further comprising:

marking the imaged target of interest by spraying one of the disturbed ground patches with an explosive discoloration agent.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,322,917 B2
APPLICATION NO. : 13/356532
DATED : April 26, 2016
INVENTOR(S) : Farrokh Mohamadi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page: item (54) and in the Specification: column 1 the Title should read:

INTELLIGENT DETECTION OF BURIED IEDS

On the Title Page: item (75) Inventor should read:

Farrokh Mohamadi, Irvine, CA (US)

In the Specification:

In column 2, line 52, change “TED” to --IED--

In column 5, line 31, change “RE” to --RF--

Signed and Sealed this
Twentieth Day of September, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office