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Roy et al.

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(54) **METHODS, APPARATUS AND SYSTEMS FOR ENHANCED SYNTHETIC VISION AND MULTI-SENSOR DATA FUSION TO IMPROVE OPERATIONAL CAPABILITIES OF UNMANNED AERIAL VEHICLES**

(58) **Field of Classification Search** 701/16, 701/28, 29, 33, 35, 36; 244/75.1, 158.1
See application file for complete search history.

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(57) **ABSTRACT**

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The invention provides, in some aspects, improved methods, apparatus and systems for unmanned aerial vehicle (UAV) operation that utilize multiple data links between a UAV and a control station in order to transmit control and actionable intelligence data. Such methods, apparatus and systems can be used, for example, to monitor a selected environment (e.g., an oil field or other terrain/environment of interest). In a related aspect, such data links comprise satellite communication channels.

Related U.S. Application Data

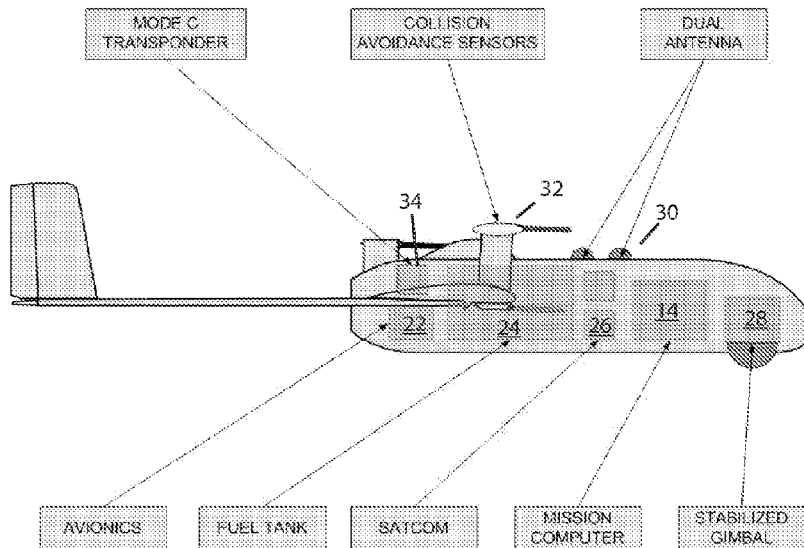
(60) Provisional application No. 60/868,784, filed on Dec. 6, 2006, provisional application No. 60/916,554, filed on May 7, 2007.

(51) **Int. Cl.**
G05D 1/00 (2006.01)

(52) **U.S. Cl.** **701/28; 701/33; 701/36; 244/158.1**

54 Claims, 13 Drawing Sheets

12 ↘



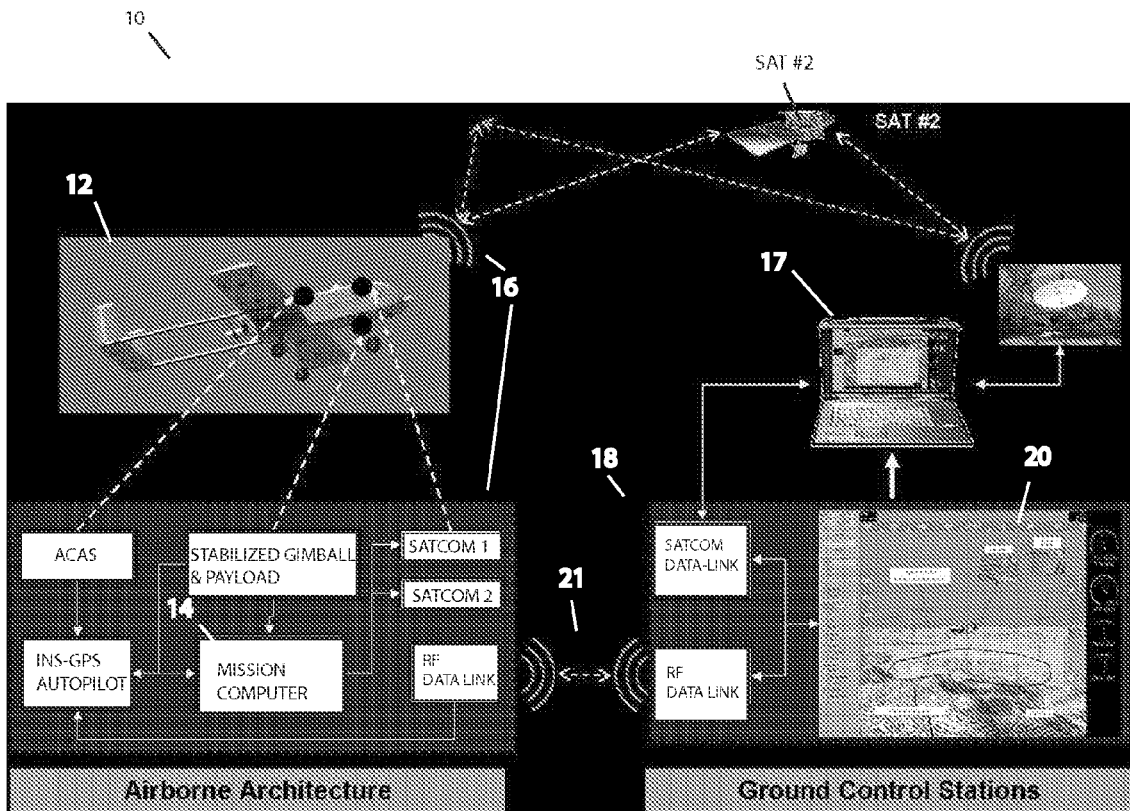


Figure 1

12 ↙

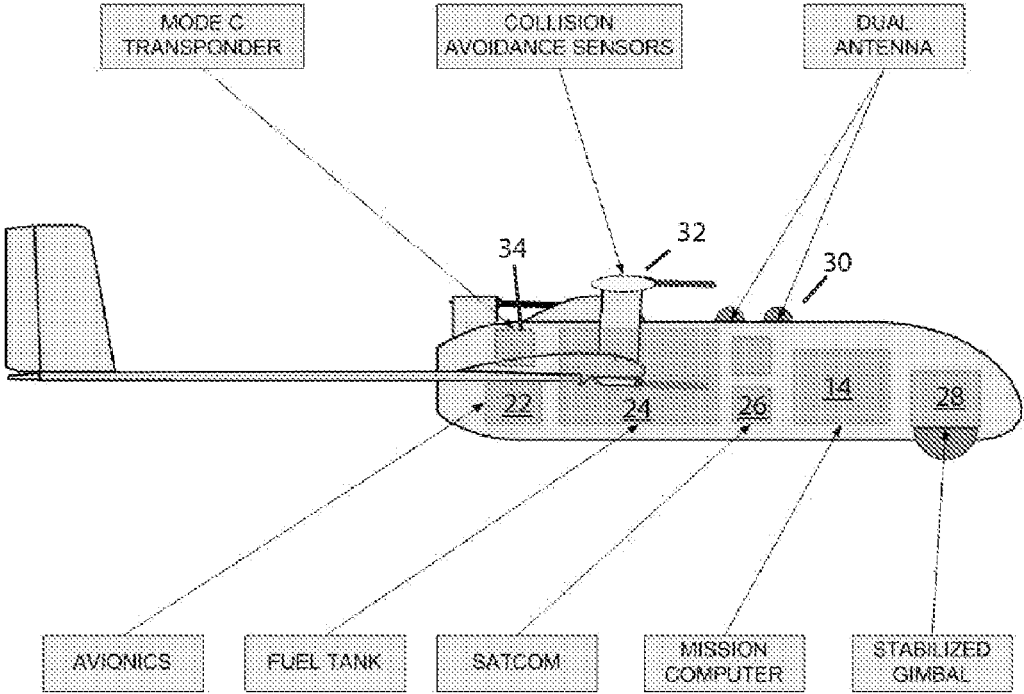


Figure 2

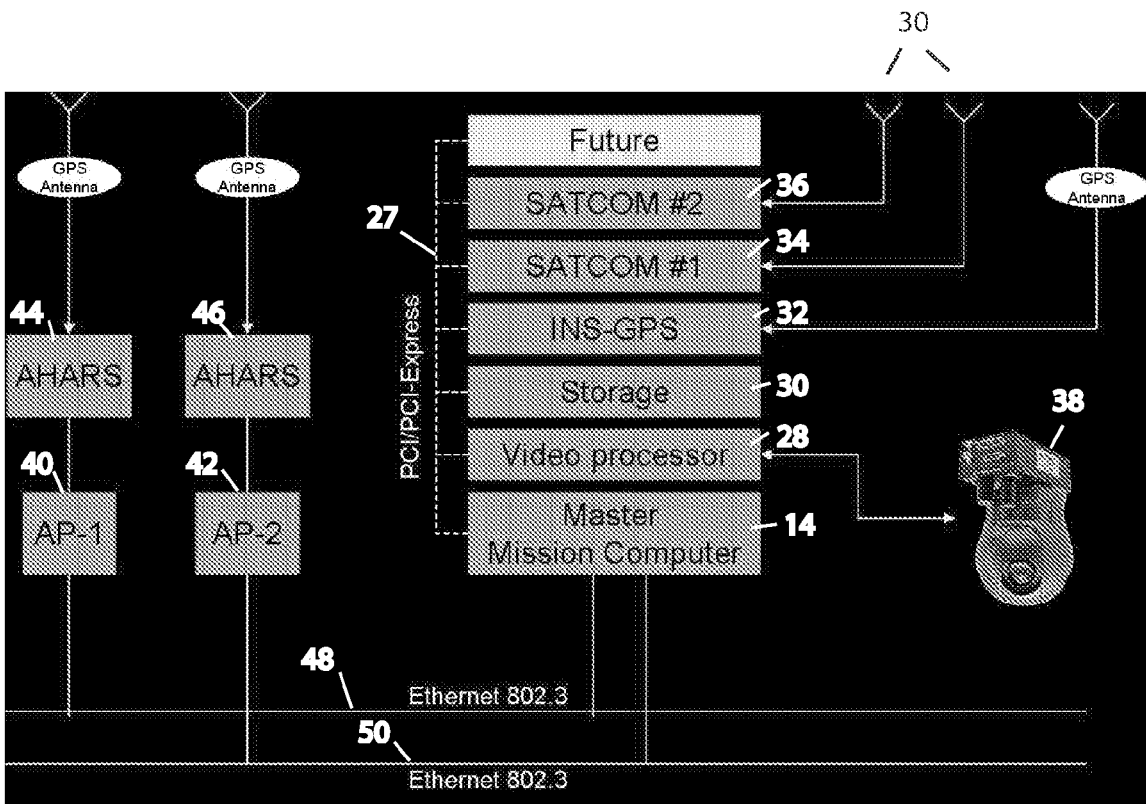


Figure 3

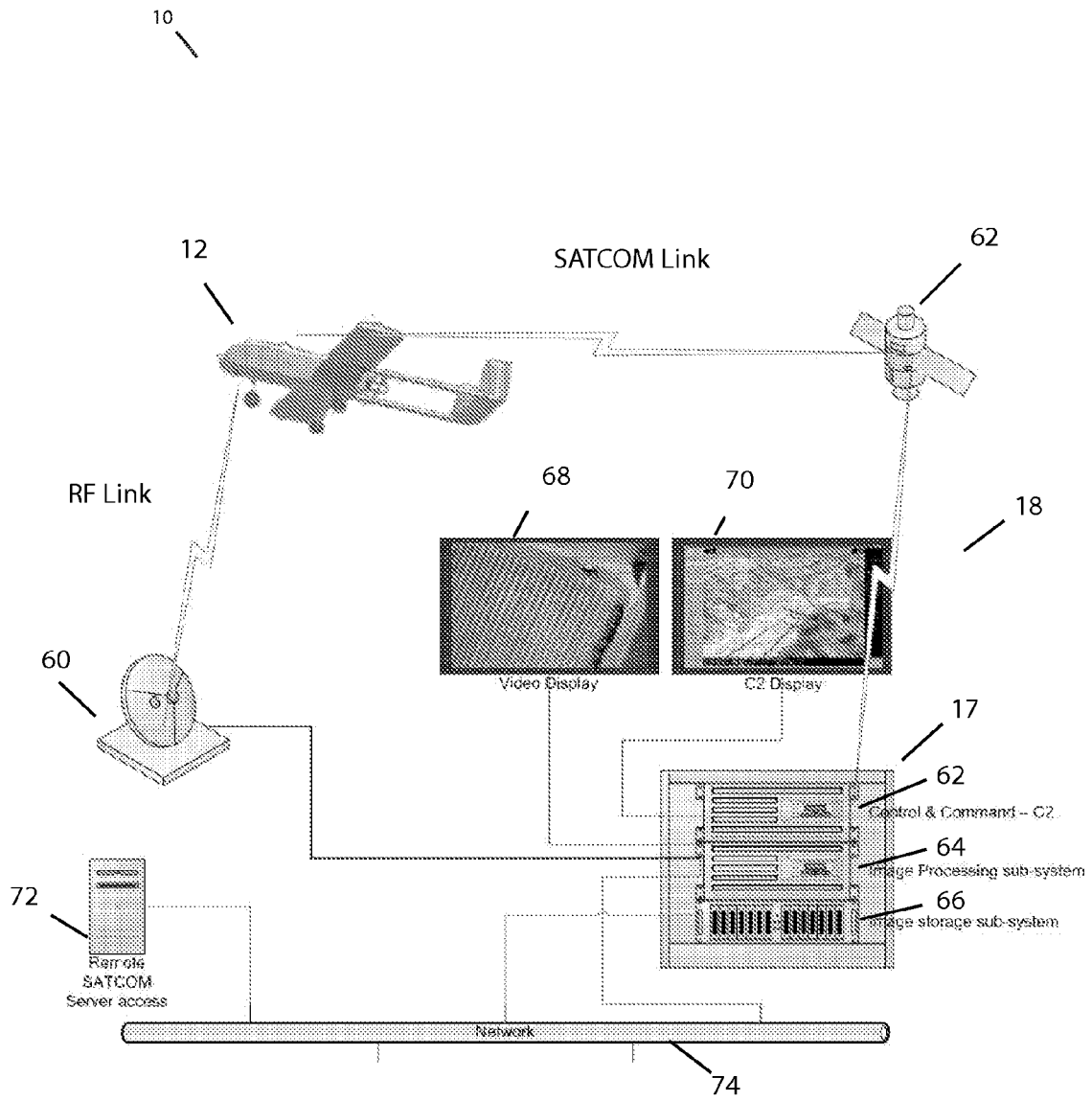


Figure 4

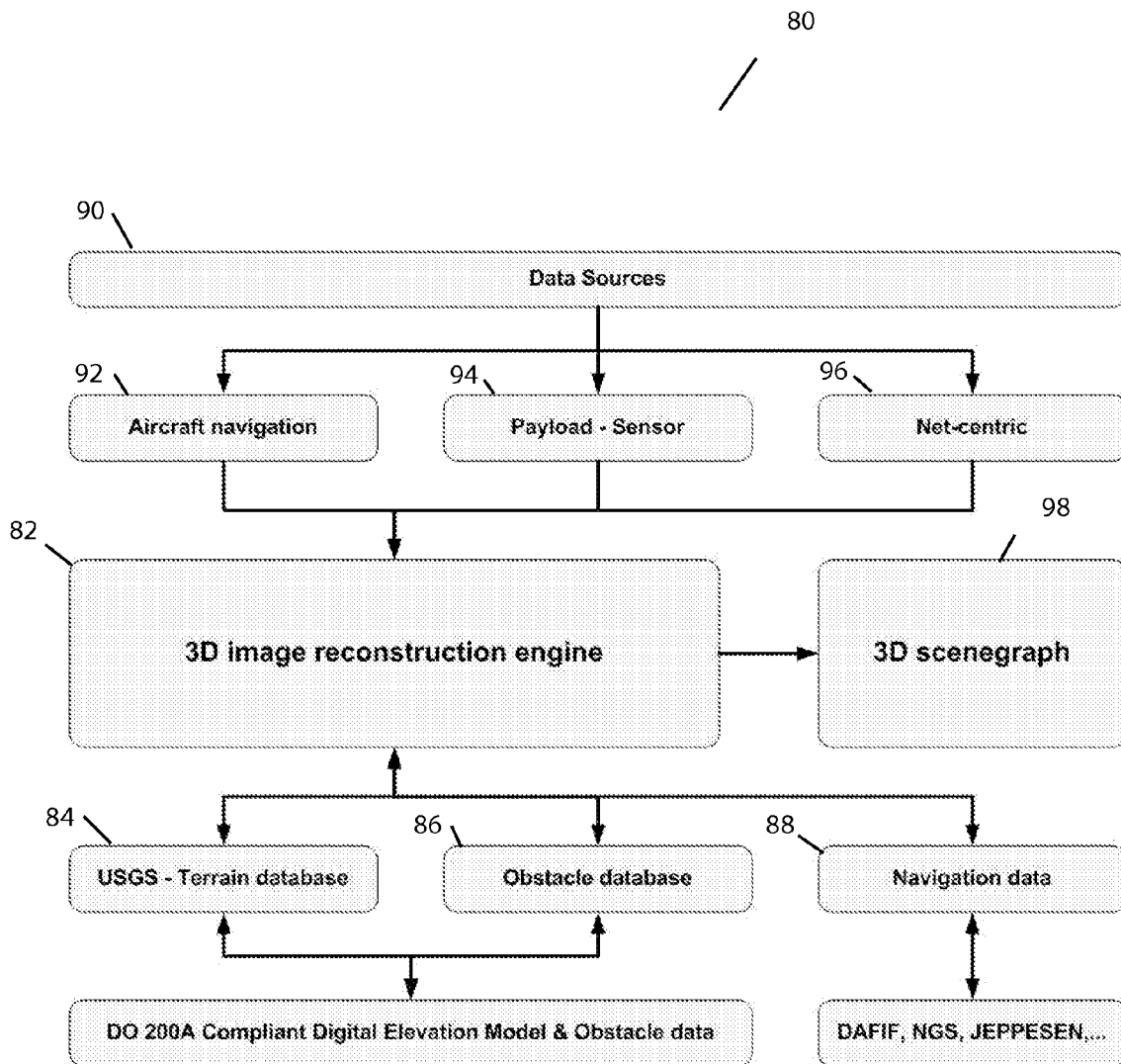


Figure 5

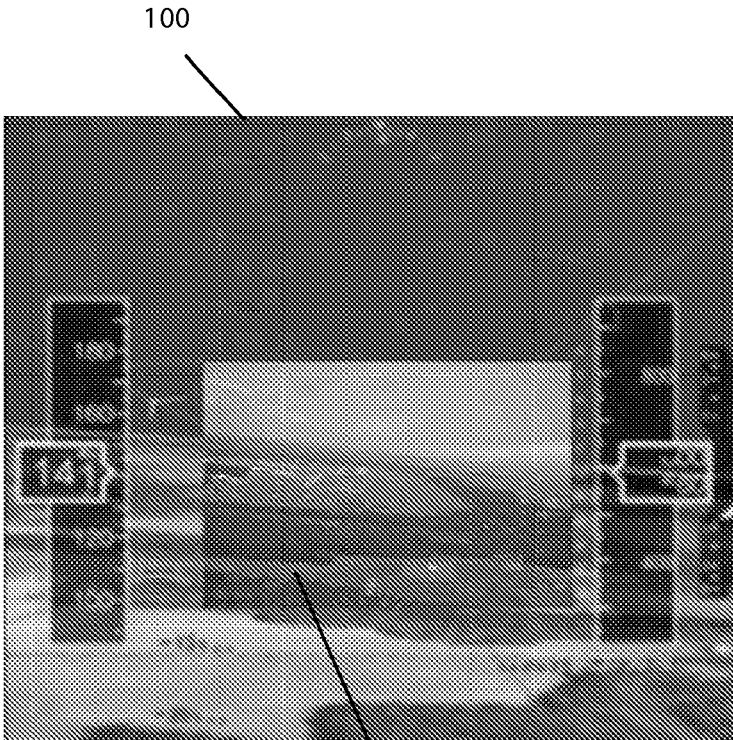


Figure 6a

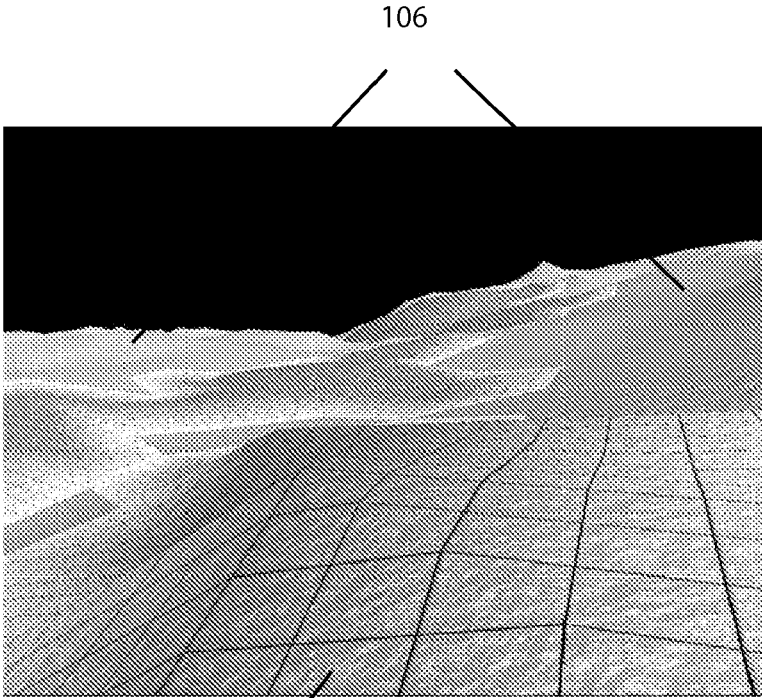


Figure 6b

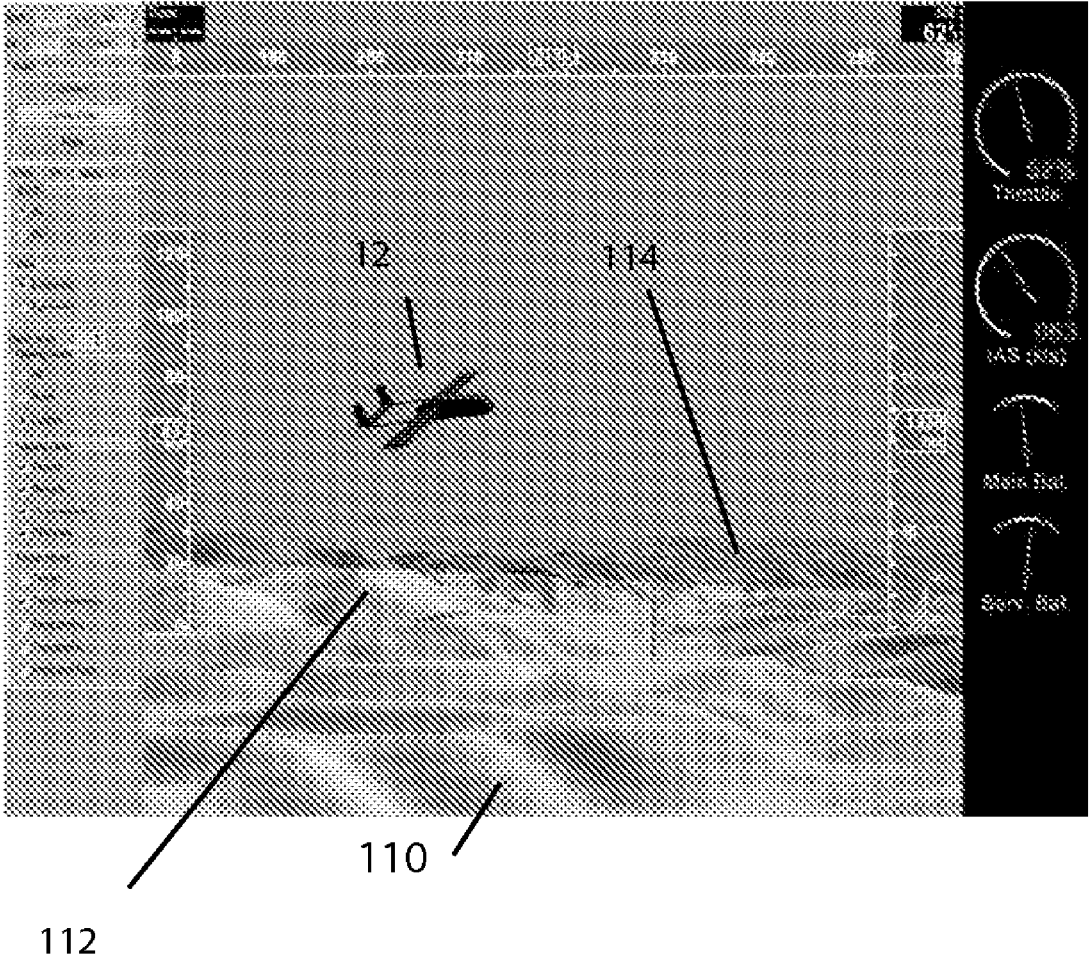


Figure 7

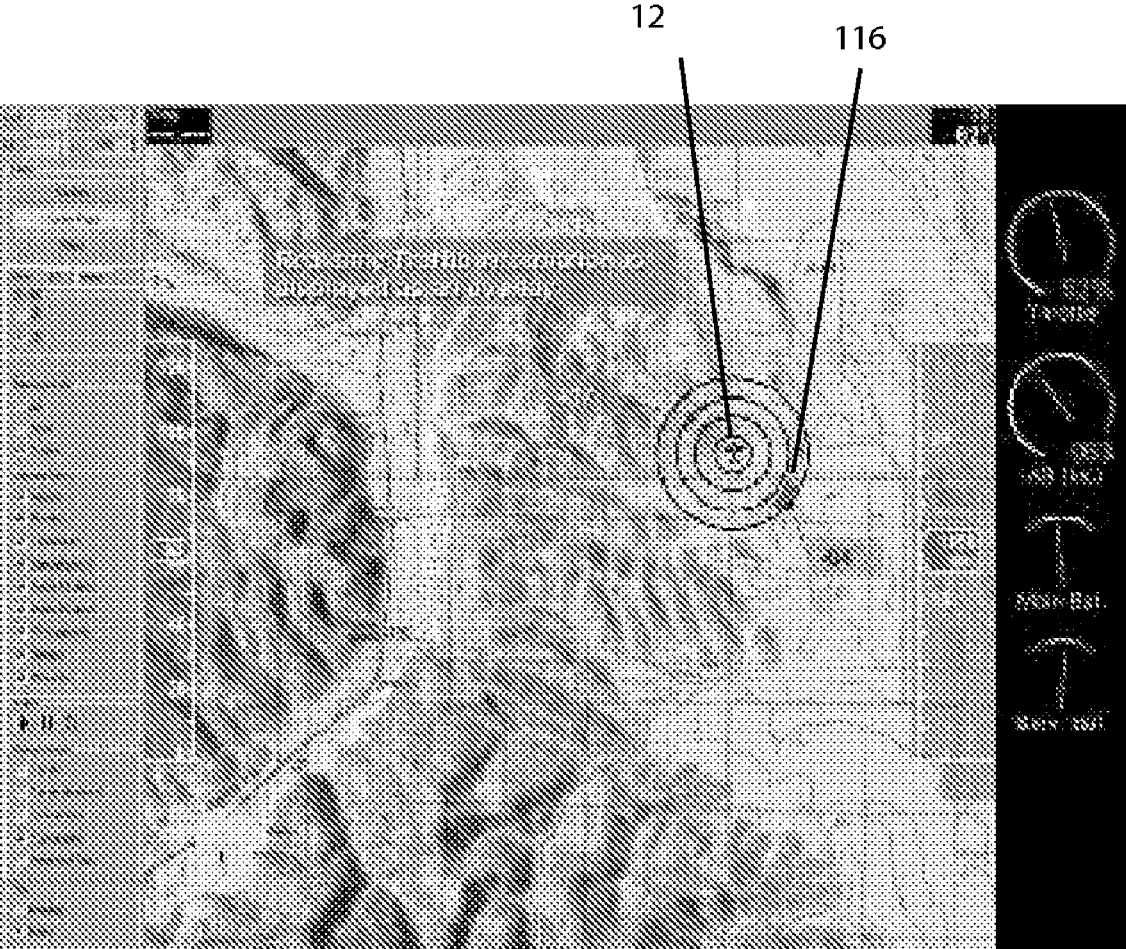


Figure 8

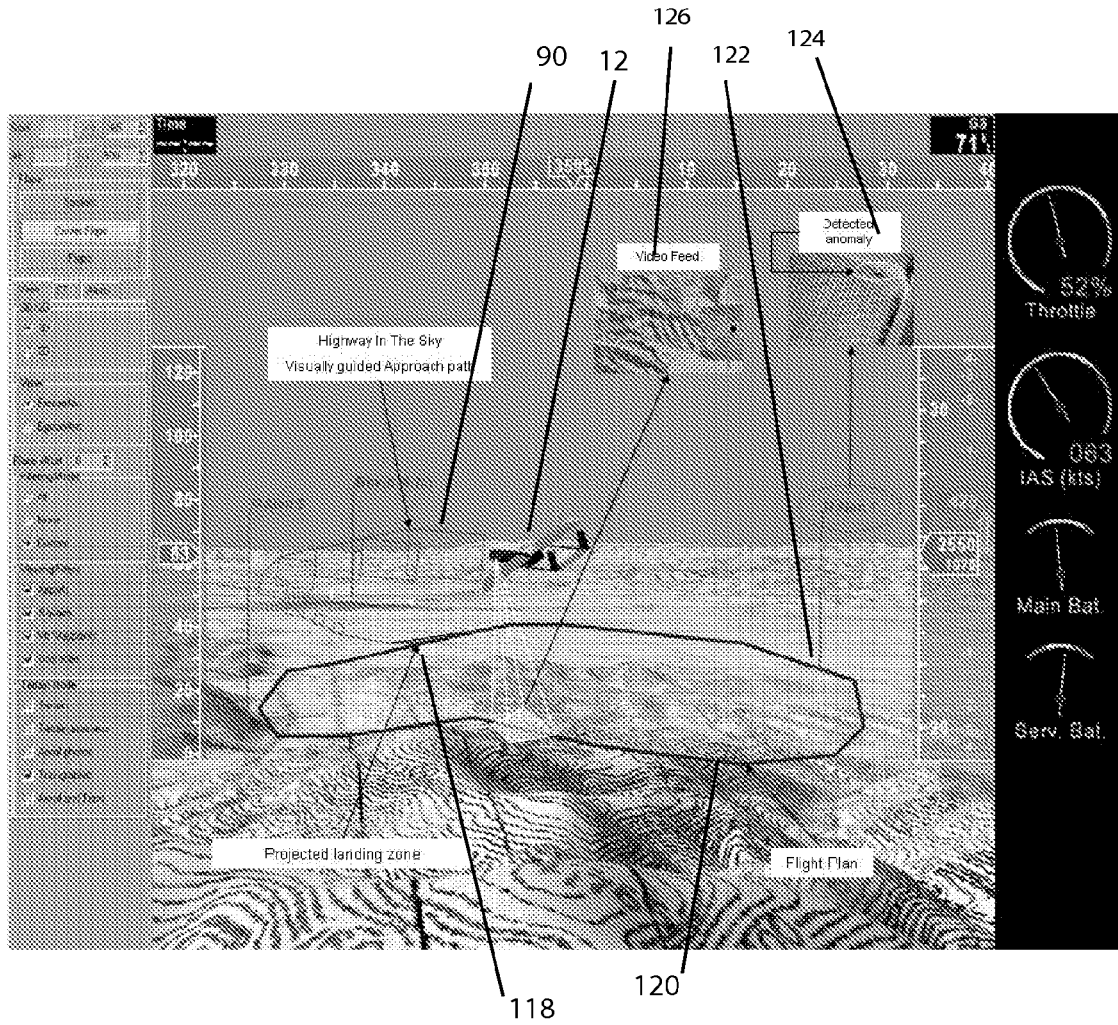
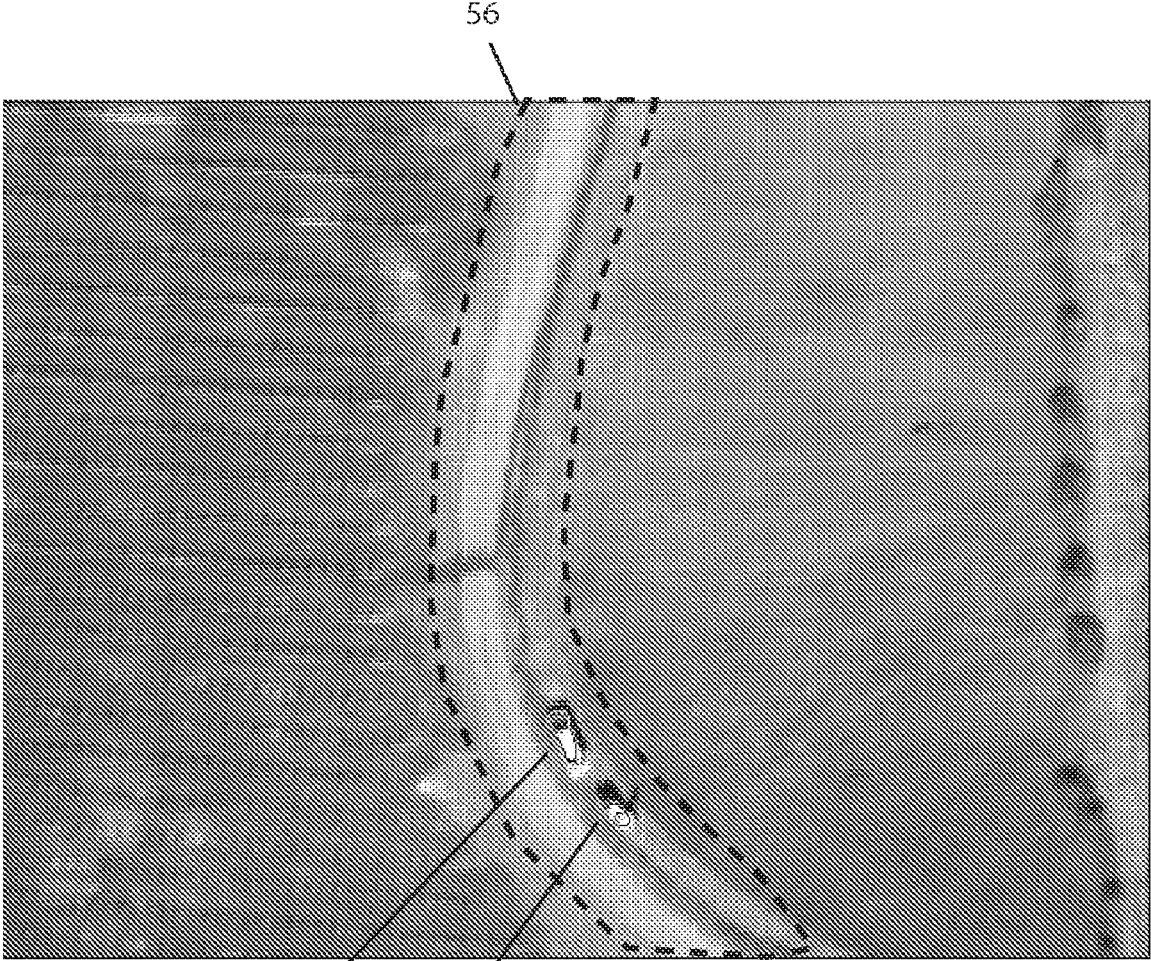


Figure 9



52

54

Figure 10

atmospheric pressure so that the operator does not need to compress the air within the cylinder when returning the carriage 526 to the launch position. Once the carriage 526 has been returned to the position shown in FIG. 5A, the actuator 510 can be readied for the next launch, for example, by charging the cylinder in which the piston operates with a compressed gas. In other embodiments, the energy of deceleration can be used to reversibly regain energy to be used during the next launch. In still further embodiments, the actuator 510 can be recharged by the carriage return crank 522. As the carriage return crank 522 is actuated, it can force the second member 528 to its original position as the carriage 526 returns. This movement can also force the piston on the actuator 510 to its starting position and restore gas pressure in the actuator 510.

FIG. 5C is a partially schematic illustration of a portion of the launch system 525 illustrating the first member 527, along with the second member 528 (shown in its pre-launch configuration in solid lines and in its post-launch configuration in dashed lines). As shown in FIG. 5C, the portion of the second member 528 to which the coupling line 535 is attached can move by distance $3x$, which is three times the distance X moved by the right most portion of the second member 528. The wedge angle between the first member 527 and the second member 528 increases by translating and pivoting the second member 528 relative to the first member 527. By increasing the wedge angle during the launch process, the carriage 526 is accelerated at a constant or nearly constant rate, even as the force from the actuator decreases near the end of the actuator's power stroke.

FIG. 5D is a graph illustrating predicted acceleration and velocity values for a carriage 526 propelled by a launch system 525 in accordance with an embodiment of the invention. In one aspect of this embodiment, the launch system 525 can provide a generally constant acceleration to the carriage 526, which instantaneously reverses (when the carriage 526 reaches the braking portion 519 described above). This acceleration profile can provide a generally uniform increase in velocity, as is also shown in FIG. 5D, up to at least the take-off velocity of the aircraft 140. In other embodiments, the carriage 526 can be propelled in manners that result in different acceleration and velocity profiles.

FIG. 5E is a partially schematic illustration of a launch system 525a configured in accordance with another embodiment of the invention and having many characteristics in common with the launch system 525 described above with reference to FIGS. 5A–5C. In one aspect of this embodiment, the launch system 525a includes a first link 518a and a second link 518b coupled between the first member 527 and the second member 528, in lieu of the block and tackle 533 and pin 532 arrangement described above. The motion of the second member 528 relative to the first member 527 can be generally similar to that described above with reference to FIGS. 5A and 5B, to provide acceleration and velocity profiles generally similar to those described above with reference to FIG. 5D.

FIGS. 6A–6B illustrate a launch system 625 configured in accordance with still another embodiment of the invention. In one aspect of this embodiment, the launch system 625 can include a first member 627 coupled to a second member 628 at a pivot point 633. An actuator 610 can be coupled to the first member 627 and the second member 628 with actuator rods 611 to force the first and second members 627, 628 apart from each other in a transverse plane. A carriage 626 can carry the aircraft 140 and can engage a first roller surface 637 of the first member 627 with first wheels 624a. The

carriage 626 can also engage a second roller surface 638 of the second member 628 with second wheels 624b.

Referring now to FIG. 6B, the actuator 610 can be activated to spread the first member 627 and the second member 628 apart from each other, forcing the carriage 626 from left to right. When the carriage 626 reaches braking portions 619 of the first and second members 627, 628, it rapidly decelerates, causing a gripper 620 to open (as indicated by arrows Y) while the aircraft 140 continues forward and is launched into flight. In other embodiments, the launch system 625 can have other arrangements.

One feature of embodiments of the launch systems described above with reference to FIGS. 5A–6B is that the “wedge action” of the first and second members relative to each other can rapidly accelerate the carriage (and therefore the aircraft 140) in a relatively short distance. An advantage of this arrangement is that the launch systems can be used in cramped quarters, including the deck of a fishing vessel or a towed trailer.

Another feature of embodiments of the launch systems described above is that the wedge angle between the first and second members can increase as they move relative to one another. This arrangement can provide a constant or nearly constant acceleration to the carriage (and the aircraft 140), even if the force provided by the actuator decreases near the end of the actuator's power stroke. An advantage of this arrangement is that the aircraft 140 is less likely to be subject to sudden changes in acceleration, which can damage the aircraft 140.

Yet another feature of the launch systems described above with reference to FIGS. 5A–6B is that at least one of the first and second members can include a braking portion which rapidly and safely decelerates the carriage carried by the launch system. An advantage of this feature is that the rail length required for deceleration can be short relative to that for acceleration, and the overall length of the system can be correspondingly limited. Further details of the manner in which the carriage releases the aircraft are described below with reference to FIGS. 6C–6F.

Another feature of the launch systems described above with reference to FIGS. 5A–6B is that the number of components that move at high speed during the launch process is relatively small. For example, in a particular embodiment, the only rolling elements that are traveling at high speed are the carriage wheels, and no high speed pulleys are included. Accordingly, the potential losses associated with components moving at high speed, including losses caused by ropes attached to the carriage suddenly accelerating and decelerating (e.g., “rope slurping”) can be reduced and/or eliminated.

FIGS. 6C–6F illustrate an arrangement for supporting the aircraft 140 during launch, suitable for use with any of the launch systems described above. In one embodiment, shown in FIG. 6C, the arrangement can include a carriage 626 having a gripper 620 which includes two gripper arms 618. Each gripper arm 618 can include a forward contact portion 617a and an aft contact portion 617b configured to releasably engage the fuselage 141 of the aircraft 140.

FIG. 6D is a front end view of the carriage 626 and the aircraft 140. As shown in FIG. 6D, each contact portion 617a can have a curved shape so as to conform to the curved shape of the fuselage 141. Each gripper arm 618 can be pivotably coupled to the carriage 626 to rotate about a pivot axis P. In one aspect of this embodiment, each pivot axis P is canted outwardly away from the vertical by an angle Z. As described in greater detail below, this arrangement can prevent interference between the gripper arms 618 and the

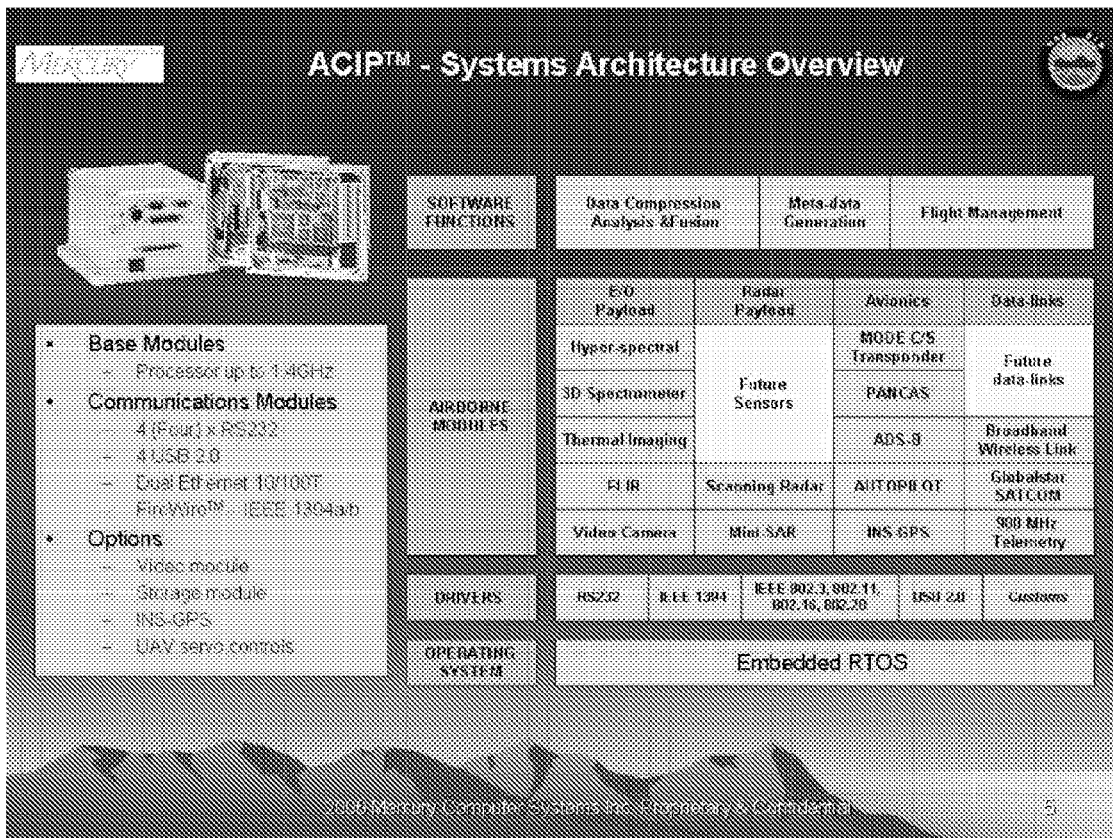


Figure 12

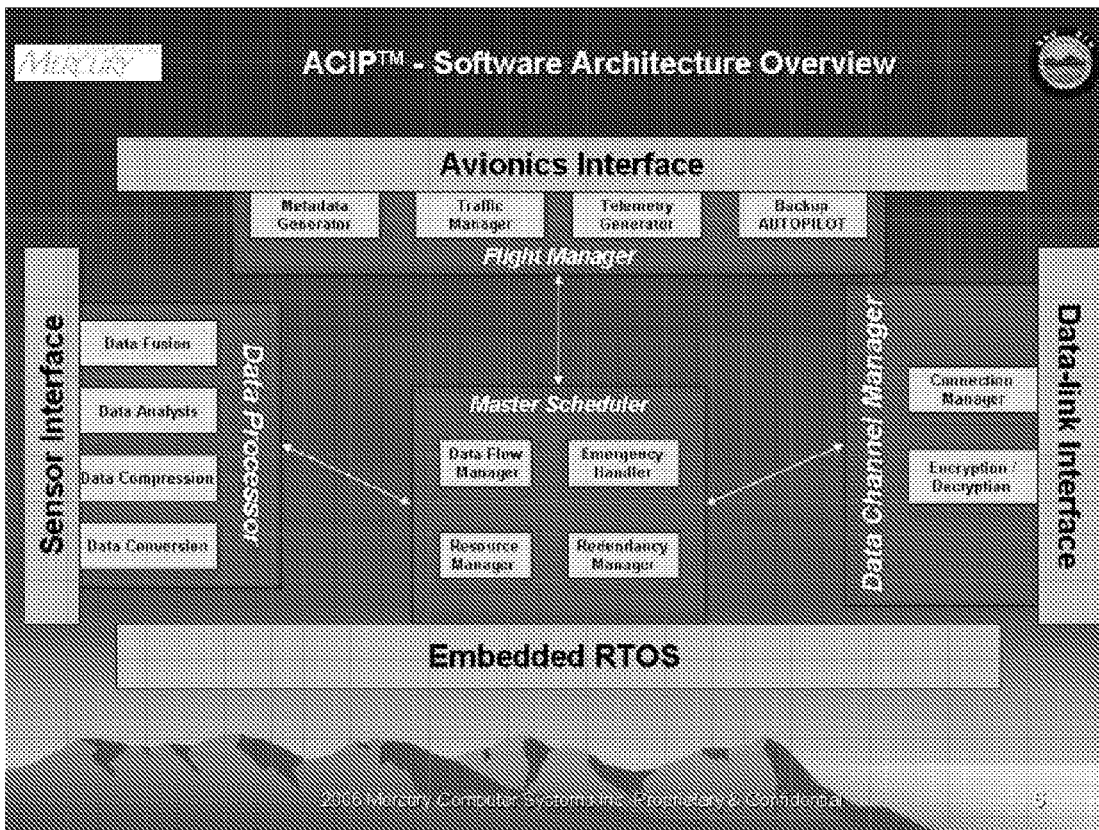


Figure 13

METHODS, APPARATUS AND SYSTEMS FOR ENHANCED SYNTHETIC VISION AND MULTI-SENSOR DATA FUSION TO IMPROVE OPERATIONAL CAPABILITIES OF UNMANNED AERIAL VEHICLES

This application is related to, and claims the benefit of filing, of U.S. Provisional Patent Application Ser. No. 60/868,784, filed Dec. 6, 2006, entitled "Airborne Component Integration Processor and System," U.S. Provisional Patent Application Ser. No. 60/916,554, filed May 7, 2007, entitled "Methods, Apparatus and Systems for Enhanced Synthetic Vision Systems and Multi-Sensor Data Fusion to Improve Operational Capabilities of Unmanned Aerial Vehicles," the teachings of both of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Unmanned aerial vehicles (UAVs) have demonstrated great potential for various surveillance and reconnaissance military applications due to their growing capabilities and lower cost of operation. However, there are a number of technical constraints hindering their widespread acceptance. These include issues associated with operational effectiveness, use of data, and National Airspace access, to name a few.

Thus, for example, small UAVs have substantially reduced the cost of Line Of Sight (LOS) surveillance and reconnaissance missions, but still have difficulties integrating data-link bandwidth limitations, Beyond Line Of Sight (BLOS), traffic detection and avoidance, as well as more airborne intelligence with navigation capabilities. Most or all of these issues have not really been resolved with either reliable and/or affordable technology.

An object of the invention is to provide improved methods, apparatus and systems for unmanned aerial vehicle operation. A related object is to provide such improved methods, apparatus and systems as can be used with small UAVs.

Still further objects of the invention provide such improved methods, apparatus and systems as improve small UAVs' mission capabilities, as well as their provision of actionable intelligence.

SUMMARY OF THE INVENTION

The foregoing are among the objects attained by the invention which provides, in some aspects, improved methods, apparatus and systems for unmanned aerial vehicle (UAV) operation that utilize multiple data links between a UAV and a control station in order to transmit control and actionable intelligence data. Such methods, apparatus and systems can be used, for example, to monitor a selected environment (e.g., an oil field or other terrain/environment of interest). In a related aspect, such data links comprise satellite communication channels.

Related aspects of the invention provide such methods, apparatus and systems that use a first of the data links (e.g., satellite communication channel) for transmission of command, control and/or system monitoring data. A second one of those data links can be used for transmission of actionable intelligence data.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the UAV includes an onboard transceiver (e.g., low-orbit satellite modem) that transmits to the control station the aforementioned command, control, system monitoring, and/or actionable intelligence data.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the UAV includes an airborne imaging computer that acquires and/or analyzes images from onboard cameras (and other sensors). In a related aspect, the airborne imaging computer identifies actionable intelligence data, e.g., via anomaly detection.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer discerns coordinates of the detected anomalies and/or other actionable intelligence.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer effects transmission of actionable intelligence data and the coordinates to the control station. In a related aspect of the invention, such actionable intelligence data can include images, e.g., video and/or stills, acquired by the UAV's onboard sensors. In a further related aspect of the invention, such actionable intelligence data can include portions of video and/or still images representing anomalies in a terrain/environment in a vicinity of the UAV.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer (or other component of the UAV) transmits coordinate data to the control station over the aforementioned first data link, and images comprising the actionable intelligence data over the aforementioned second data link.

Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, that includes functionality for detecting anomalies in the images and/or other sensor data.

Further aspects of the invention provide improved methods, apparatus and system for UAV operation, e.g., as described above, wherein the control station includes a synthetic vision display system that enhances a synthetic display of terrain over which the UAV is flying and/or in which an anomaly is detected with image and/or coordinate data received from the UAV. This can be used, for example, to (i) eliminate the necessity of transmitting to the control station a high-bandwidth and/or real-time stream of images representing, e.g., the terrain/environment in a vicinity of the UAV, in favor of only selected events detected in that vicinity, and (ii) focus a control station operator's attention when an actionable intelligence event occurs.

Further aspects of the invention provide improved methods, apparatus and system for UAV operation, e.g., as described above, wherein the synthetic vision display system includes a terrain database for rendering a synthetic image based on a location of the UAV (e.g., as indicated via GPS coordinates transmitted over one or more of the data links).

Further aspects of the invention are evident in the drawings and the description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention may be attained by reference to the drawings, in which:

FIG. 1 depicts an autonomous small unmanned vehicle system (SUAS) according to one practice of the invention;

FIG. 2 depicts further details of an exemplary aircraft of the type used in one practice of the invention;

FIG. 3 depicts in further detail the interrelationships among selected ones of the aircraft-based elements shown in FIG. 1;

FIG. 4 depicts the SUAS system of FIG. 1 from the perspective of the ground control station;

FIG. 5 depicts a flow diagram of a synthetic vision system according to the invention;

FIG. 6a depicts a FLIR-based Enhanced Synthetic image of the type generated by a system according to the invention;

FIG. 6b depicts a terrain morphing image of the type generated by a system according to the invention;

FIG. 7 depicts dynamic terrain awareness image of the type generated by a system according to the invention;

FIG. 8 depicts a traffic display overlay image of the type generated by a system according to the invention;

FIG. 9 depicts an integrated synthetic image of the type generated by a system according to the invention;

FIG. 10 depicts an image generated in connection with an anomaly-based alarm by a system according to the invention; and

FIGS. 11-13 depict aspects of an airborne processor that can be used with practice of the invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

FIG. 1 depicts an autonomous small unmanned vehicle system (SUAS) according to one practice of the invention suitable for remote inspection, surveillance, reconnaissance and other applications (collectively, “surveillance”). The illustrated system 10 comprises the following integrated elements, though, it will be appreciated that other embodiments may include other elements, instead or in addition, and/or may include subsets of those shown below:

1. A small unmanned aircraft 12 capable of autonomous flight and equipped with an airborne video camera.
2. An airborne computer 14 that is capable of acquiring, compressing, storing and processing analog and digital video.
3. Anomaly detection software executing on computer 14.
4. Airborne low-orbit satellite modem(s) 16.
5. A ground control station 18 connected via satellite with software capable of visualizing navigation and payload data as an overlay to three dimensional terrain display 20.

The Unmanned Aircraft

Unmanned aircraft 12 (alternatively, referred to as the “UAV”) may be of the type commonly known for use in SUAS systems (e.g., by way of non-limiting example, the Vector P UAV available from Intellitech Microsystems). Though craft 12 utilized in the illustrated embodiment is small of size (relative to manned aircraft), other embodiments may utilize larger craft, while other embodiments may utilize craft even smaller than that depicted in the drawings. Moreover, although illustrated craft 12 is unmanned (i.e., does not have an onboard human pilot), in other embodiments such a pilot and/or personnel other may be onboard. Still further, although illustrated craft 12 is an aircraft, it will be appreciated that in other embodiments, craft 12 may operate in other environments, e.g., water, land, and so forth. Yet still further, while illustrated craft 12 is intended for operation remote from the ground control station, in other embodiments the craft 12 may be used for nearby operations—albeit, for example, operations in which it is less preferable to expose ground control station operators and/or their equipment). For sake of simplicity, both remote and nearby operations are referred to herein as “remote.”

FIG. 2 depicts further details of an exemplary aircraft 12 of the type used in one practice of the invention. As shown in the drawing, illustrated craft 12 includes avionics section 22, fuel

tank 24, satellite communications subsystem 26, stabilized gimbal assembly 28, satellite antenna structure 30, collision avoidance sensors 32 and mode C transponder 34, all of the type known in the art as adapted in accord with the teachings hereof. Thus, for example, antenna structure 30 of the illustrated embodiment comprises dual antennae, capable of supporting dual low-orbit (or other) satellite communications (e.g., with one antenna supporting the communication of command & control information, and the other antenna supporting communication of alarms and related data). In order to conserve space and power, the individual antenna used in the illustrated embodiment are “small” disk-shaped antenna having diameters of approximately 3” or less. Other embodiments may vary in this regard, e.g., utilizing antenna of diameters of 4” or less, 5” or less, 10” or less, and so forth. As noted above, other embodiments of the invention may include elements other than those shown in FIG. 2, instead or in addition, and/or may include subsets of those shown in the drawing.

Aircraft 12 additionally includes mission computer 14, as shown, which can comprise a portable computer or other digital data processor of the type commercially available in the marketplace as programmed and otherwise adapted in accord with the teachings hereof. Preferred such computers are ruggedized for tolerance of inflight conditions and include graphics cards to facilitate anomaly detection and other processing functions described herein.

FIG. 3 depicts in further detail the interrelationships among selected ones of the aircraft-based elements shown in FIG. 1. Particularly, as shown in FIG. 3, mission computer 14 is coupled by way of a bus 27 to video processor 28, storage unit 30, inertial navigation system (INS)—global positioning system (GPS) system 32, and dual satellite communications modems 34, 36. Elements 28-36 are of the respective types known in the art, as adapted in accord with the teachings hereof. Thus, again, for example, although the prior art typically provides a single SATCOM modem, the illustrated embodiment utilizes two such modems 34, 36 (each supporting low-speed communications, e.g., at a rate of approximately 9600 bps—as discussed elsewhere herein), e.g., one supporting the transfer of command & control information with the GCS and the other supporting the transfer of alarms, alarm images and related data with the GCS. By way of further example, storage unit 30 may comprise an on-board disk drive that stores a video stream of the entire flight which can then be post-processed using change-detection to identify possible threats that were too subtle to detect in real time.

Bus 27 of the illustrated embodiment is a PCI/PCI-Express bus, though, in other embodiments, other bus types or communication media may be used, instead or in addition.

With further reference to the drawing, INS-GPS unit 32 is coupled to a GPS antenna, as shown. In addition, mission computer 14 is coupled to airborne video camera 38 (or other image acquisition device) by way of video processor 28. The video camera 38, which is disposed on or otherwise coupled to craft 12, acquires images of terrain, airspace, or other scenes in a vicinity of the craft 12 (and, more particularly, in a field of view of the camera 38) suitable processing by the mission computer 14 and/or transmission to the GCS 18). Video camera 38 may be of the type commonly used in airborne or other remote image acquisition (and, preferably, video image acquisition) applications and, particularly, of the type that generates a “true color” three-band (RGB) image. Video processor 28 may be of the type commonly used for interfacing a video (or other) image acquisition device with a computer for purposes of control and data transfer. Coupling

between the video processor **28** and the video camera **38** may be via FireWire or other interface (wired, wireless or otherwise) known in the art.

Mission computer **14** is also coupled with autopilot systems **40, 42** (each of the type known in the art) which, themselves, are coupled to airborne heading-attitude reference systems (AHARS) **44, 46** and GPS antenna, as shown. In the illustrated embodiment, communications between the mission computer **14** and the autopilot systems **40, 42** is supported by dual ethernet channels **48, 50**, though, in other embodiments, other media may provide such support.

Although in the illustrated embodiment, mission computer **14**, video processor **28** and video camera **38** are disposed on craft **12** and in wired communications with one another, in other embodiments one or more of those elements be disposed elsewhere. Thus, for example, camera **38** may be disposed on craft **12**, while mission computer **14** and video processor **28** are disposed on another craft (not shown) or intermediate station (not shown) in sufficient proximity to permit transmission of high resolution images from camera **38** to the mission computer **14** for processing and anomaly detection thereby.

In the illustrated embodiment, camera **38** is housed in the gimbaled assembly **28**, which is attached to the underside of the craft's fuselage. The gimbal **28** preferably includes an integrated Global Positioning System/Inertial Measurement Unit system (GPS/IMU) and is stabilized using feedback logic that links the gimbal's servo-motors and the IMU under software control. Furthermore, the gimbal's integrated GPS can be used to determine the geographical location of the center of the video image.

Anomaly detection software executing on mission computer **14** of the illustrated embodiment utilizes both spectral and spatial methods, as well as supervised and unsupervised classification techniques. It is based on the SSRX (subspace RX) algorithm (or methodology) known in the art (e.g., as disclosed in Winter et al, "Hyperspectral image sharpening using multispectral data," Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XI, Proceedings of the SPIE, Volume 5806, pp. 794-803 (2005)) and on the open source RXD algorithm (or methodology), e.g., as disclosed in I. S. Reed and X. Yu, "Adaptive multiple-band CFAR detection of an optical pattern with unknown spectral distribution," IEEE Trans. Acoust., Speech, Signal Processing, vol. 38, pp. 1760-1770, October 1990, that was originally developed to detect anomalies in images generated by hyper-spectral cameras.

In the illustrated embodiment, SSRX is novelly applied to the RGB color video from camera **38** (and video processor **28**), and it is adapted to identify anomalies whose Mahalanobis distances correlate with actual or suspected alarm instances (e.g., intrusions or other suspect patterns in video images by the camera **38**), e.g., as determined empirically or otherwise based on the expected content of video images in which anomalies are being detected.

In the illustrated embodiment, the occurrence of false alarms (i.e., signaling of false anomalies) otherwise evidenced in the SSRX image (i.e., the image resulting from SSRX processing) is further eliminated through spatial filtering. This is done using image pyramids of the type known in the art. More particularly, it is done by cycling through image pyramids in the SSRX image. This eliminates artifacts and objects of small width in the filtered image that results from the SSRX processing—and, conversely, emphasize objects in that filtered image that have a blob-like geometry. Pixels within regions of the image that remain after such spatial filtering are, then, highlighted in the original video image of

the scene so as to call them out as alarms. More generally, such highlighting is performed still images generated from the original video image,

A further appreciation of the anomaly detection software utilized in the illustrated embodiment may be attained by reference to the Appendix filed herewith.

The Ground Control Station

FIG. 4 depicts the SUAS system **10** of FIG. 1 from the perspective of the ground control station. Although in the illustrated embodiment, this is contemplated to be a station disposed at a ground-based site, in other embodiments it may be disposed in the air or elsewhere. Regardless, for sake of simplicity, it shall be referred to herein as a "ground control station" or "control station."

As noted previously, the system **10** includes a unmanned craft **12** that is coupled for communications with a ground control station **18** via radio frequency (RF) and satellite (SATCOM) links. In the drawing, the former is graphically depicted by a dish antenna **60** coupled with computer **17** at the GCS, though, those skilled in the art will appreciate that such an RF (of alternate) link may be supported in other ways. Likewise, the latter is graphically depicted by a satellite **62** (e.g., supporting both the transfer of command & control information, as well as alarms, alarm images and related data), though, such an alternate link may be provided instead or in addition. Indeed, as noted above, in the embodiments of FIGS. 1-3, dual satellite links are provided between the craft **12** and the GCS **18**.

Computer **17** comprises a portable computer (e.g., of the laptop, ruggedized backpack portable computer, or other variety) of the type commercially available in the marketplace as programmed and otherwise adapted in accord with the teachings hereof. To that end, illustrated computer **17** includes command and control subsystem **62**, image processing subsystem **64** and image storage subsystem **66**. Each of these subsystems may execute in software, firmware or otherwise on separate processor boards (e.g., co-processing cards) resident in the computer **17**, as suggested in the drawing, or, alternatively, two or more of them may execute on a common board (e.g., a motherboard).

Illustrated command and control subsystem **62** comprises logic for interfacing with the flight and other operational functions of craft **17**, e.g., over a first of the SATCOM links, to facilitate the transfer of command & control information therewith. It can be constructed and operated in the conventional manner known in the art, as adapted in accord with the teachings hereof.

Image processing subsystem **64** comprises logic for processing images relayed from the craft **12** to the GCS, e.g., over a second of the SATCOM links, as well as for generating images based on alarm data and/or images supplied by the craft **12** and/or the image storage subsystem **66**.

Illustrated image storage subsystem **66** stores images relayed from the craft **12**, as well as those generated by the image processing subsystem **64**. In addition, disk drives and other media in the image storage subsystem can retain terrain, obstacle and other databases utilized in operation of the system.

The computer **17** is coupled to one or more displays, which may be integral to the computer (as in the case of a laptop computer) or separate. Two exemplary images generated by the computer **17** on such displays are shown in the drawing: a video display image **68** depicting a scene in the vicinity of craft **12** (e.g., highlighting an alarm or other event of interest) and a command & control image **70** for situational awareness. Of course, it will be appreciate that these images are merely

shown by way of non-limiting example of the types of images generated by computer 17 for use by GCS personnel.

As further shown in the drawing, computer 17 may be coupled to remote SATCOM server 72 by way of network 74 or otherwise.

FIG. 5 is a flow diagram of a three-dimensional (3D) synthetic vision system 80 executing within image processing subsystem 64 on the computer 17 at the ground control station to permit an operator to visualize events happening in and around the operating aircraft 12 or regions in which it detects alarms. Examples of the images generated by system 80 are provided in FIGS. 6a, 6b, 7, 8, 9 and 10, discussed elsewhere herein.

The system 80 includes a 3D image reconstruction engine 82 that takes input from terrain database and obstacle databases 84, 86, respectively, as well as from navigation database 88, as shown. The engine 82 also takes input from data sources 90 that include, in the illustrated embodiment, aircraft navigation data 92, payload sensor data 94 and net-centric data 96, again, as shown. In the illustrated embodiment, the aircraft navigation data 92 and payload sensor data 94 are supplied from the craft 17, e.g., via the SATCOM link. The engine 82 generates a 3D scene graph 98, e.g., for use in generating displays, e.g., on a console coupled to GCS computer 17.

Terrain database 84 and obstacle database 86 of the illustrated embodiment comprises digital elevation model terrain and obstacle data, respectively, which may be compliant, for example, with DO 200A standards, as illustrated, or otherwise. The terrain database 84 is subject to two constraints: resolution and integrity. The Digital Elevation Model (DEM) and the Digital Terrain Elevation Data (DTED) Level drive the resolution. DTED Level [1, 2 up to 5] determines the resolution of the grid of points. For instance, DTED Level 1 is the basic resolution for elevation and/or terrain roughness in a digital format. DTED1 is a uniform matrix of terrain elevation values with post spacing every 3 arc seconds (approximately 90 meters). This level is most adequate when flying at several thousand feet and looking at mountains, but would not be suitable to land an aircraft in a non-airport environment.

Obstacle database 86 represents all forms of terrain and other items that can be a potential hazard to aircraft landing at a particular airport or otherwise traveling through airspace in which the craft is expected to fly. Television and radio antennas, tall buildings and plants, for example, are preferably precisely located and represented in the database 86 so that they can be displayed in order to be avoided.

In case of military applications, net-centric data of interest can be incorporated into the scene graphs 98 for display in scenery.

Navigation database 88 may comprise Digital Aeronautical Flight Information File (DAFIF) data on airports, nav aids, waypoints, special-use airspace, and so forth, and other navigational data from National Geodetic Survey (NGS) and Jeppesen, and so forth. Navigation databases 18 may not be very important when flying a UAV in certain military situations, but are more relevant when a small UAV is flying inside National Airspace. For instance, a small UAV flying under a FAA Certificate Of Authorization (COA) must be aware of the surrounding airspace (i.e. airport class, communication requirements, approaches, way-points, procedures, radio frequencies etc.)

Operation

Most prior art UAVs send video in real time to their associated GCS using a line-of-sight (LOS) data link. The bandwidth limitations of small UAVs make beyond-line-of-sight (BLOS) operations nearly impossible using commercial,

low-orbit satellite communications (SATCOM), which are typically limited to 9600 bps (bytes per second) throughput and, hence, are considered to be “low speed” links (e.g., relative to modern network and data link communications speeds).

The illustrated embodiment overcomes these limitations utilizing the architecture shown in FIGS. 1 and 4. The mission computer 14 uses anomaly detection software to identify high-risk targets in the video image acquired by camera 38 (and video processor 28) and to send alarms (or “actionable intelligence” data) to the GCS using the SATCOM link. That link, in the illustrated embodiment, is low-speed, i.e., it has a throughput of 9600 bps, though, other embodiments may vary from this. These alarms can identify the actual or suspected nature of the anomaly, as well as the location where it was detected. In addition, the alarm can be supplemented by a highly compressed color image that is transmitted to the GCS via the SATCOM link and that shows both an entire video frame including the anomaly. Alternatively, or in addition, if the craft 12 is within line-of-sight of the GCS 18, the alarm can be supplanted via an image or video stream transmitted from the craft to the GCS via the RF data link. The alarm and, if available, the corresponding image are displayed by computer 17 at the GCS, along with locational information derived from the on-board integrated GPS/IMU system—or, in preferred embodiments, along with a three-dimensional synthetic image constructed by system 80 utilizing the terrain, obstacle and/or navigation databases of a scene of the terrain (or other region) in which the alarm occurred.

Alternatively, or in addition, the system 80 can utilize inflight navigational data supplied by the craft 12, in conjunction with data from the terrain, obstacle and/or navigational databases, to generate three-dimensional synthetic images of the airspace and/or terrain in a vicinity of the craft 12. Those images can be enhanced to facilitate operational awareness as discussed below.

In operation, the craft 12 is launched and recovered using radio control (RC) in the conventional manner known in the art. Once stable flight has been established, control is transferred to one of the on-board autopilot systems 40, with the other autopilot system 42 serving as a backup. The autopilots 40, 42 of the illustrated embodiment are preprogrammed with way points that trace the location of a corridor or other region over which flight is to occur. Such a corridor may be, for example, a right-of-way for electricity, crude oil, petroleum, natural gas, and so forth, requiring inspection. The location of one or more emergency recovery areas may also be pre-programmed into the autopilots in case emergency situations occur.

The way points as well as other autopilot functions can be altered in flight from the ground control station (GCS) via the satellite communications (SATCOM) link, shown here supported by onboard modems 34, 36 and antenna 30, as well as by the “SATCOM Data-Link” depicted in GCS 18. This capability can be used when the on-board real-time processor 14 detects an alarm in the corridor or other region being surveyed and the GCS operator decides another look is required. The GCS-based operator can then instruct the craft (via the SATCOM link) to fly a circular pattern centered on the alarm’s location and keeping the gimbaled camera aimed at that location.

As noted above, the mission computer 14 uses the anomaly detection software to identify high-risk targets in the video image acquired by camera 38 (and video processor 28) and to then raise an alarm to the operator at the GCS 18 via trans-

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SYSTEM AND METHOD FOR OPTIMIZED UNMANNED VEHICLE COMMUNICATION USING TELEMETRY

FIELD

The present disclosure relates to the operation of unmanned vehicles, and more particularly to a system and method for optimizing the RF telemetry capability of a UAV.

BACKGROUND

The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

Unmanned Aerial Vehicles (UAVs), alternatively Unmanned Air Vehicles, are growing in importance for both military and non-military applications. UAVs typically make use of an on-board antenna, and more typically an omnidirectional on-board antenna, to wirelessly transmit information back to a ground station or base station. Typically, extra power is used to transmit Radio Frequency (RF) signals from the UAV beyond what might otherwise be needed because of various factors that might negatively influence the integrity of the RF link between the base station and the UAV. Such factors could be the changing attitude of the UAV as it flies, or possibly topographic obstructions, or even localized weather conditions (e.g., thunderstorms), that can be expected to significantly degrade the RF link between the UAV and the base station. For this reason, the transmit power used for the RF transmitter is set to a value that, during many times of use of the UAV, will be significantly more than what is needed. This factor limits the range of the UAV because excess electrical power from the UAV's on-board battery will be utilized by the on-board RF system during a given mission or operation.

The need to use extra power with an omnidirectional antenna on a UAV also gives rise to another, sometimes undesirable feature, and that is the detectability of the UAV (or interception of RF communications radiated from it) by other electronic detection systems. The use of an omnidirectional antenna broadcasts the RF signals transmitted by the UAV in an omnidirectional pattern that may facilitate radio-location of the vehicle and/or interception of communications.

SUMMARY

In one embodiment the system comprises an unmanned vehicle and a communications station located remote from the unmanned vehicle. The unmanned vehicle may include a first wireless communications system and a first directional antenna for wirelessly communicating with the remote communications station. A first antenna control system on the unmanned vehicle tracks the remote communications station and aims the first directional antenna, in real time, at the remote communications station during wireless communications with the remote communications station. The remote communications station may include a second wireless communications system and a second directional antenna for wirelessly communicating with the unmanned vehicle, and a second antenna control system that tracks the unmanned vehicle and aims the directional antenna at the unmanned vehicle, in real time, during wireless communications with the unmanned vehicle.

In another aspect of the present disclosure an unmanned vehicle is disclosed. The unmanned vehicle comprises a wireless communications system and a directional antenna for facilitating wireless communications with a remote sub-

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system. An antenna control system is included that aims the directional antenna to track the remote subsystem during wireless communications with the remote subsystem.

In another aspect of the present disclosure a base station for wirelessly communicating with a remote mobile vehicle is disclosed. The base station includes a wireless communications system and a directional antenna for wirelessly communicating with the remote mobile vehicle. An antenna control system is included that tracks the remote mobile vehicle and maintains the second directional antenna aimed at the remote mobile vehicle during wireless communications with the remote mobile vehicle.

In another aspect of the present disclosure a method for communicating between a moving unmanned vehicle and a remote communications station is disclosed. The method may include using an unmanned vehicle to wirelessly communicate with the remote communications station and controlling a first directional antenna of the unmanned vehicle such that the first directional antenna tracks the remote communications station in real time. A second directional antenna is used at the remote communications station to track the unmanned vehicle in real time.

In still another aspect of the present disclosure a method for wirelessly communicating with an unmanned vehicle is disclosed. The method may comprise using a directional antenna on the unmanned vehicle for facilitating wireless communications with a remote subsystem. An antenna control system on the unmanned vehicle may be used to aim the directional antenna to track the remote subsystem during wireless communications with the remote subsystem.

Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

FIG. 1 is a high level block diagram of an overall system in accordance with one embodiment of the present disclosure; and

FIG. 2 is a flowchart illustrating major operations performed by the system of FIG. 1 when communicating between an unmanned vehicle and a remote communications station.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

Referring to FIG. 1, there is shown a communications system 10 for enabling communications between an unmanned vehicle 12 and a remote communications station 14. In this example the unmanned vehicle is shown as an unmanned aerial/air vehicle (hereafter referred to as a "UAV"), although it will be appreciated that the present disclosure could just as readily be employed with land vehicles or marine vessels. Thus, the following discussion and claims will be understood as encompassing any type of mobile vehicle, whether of the airborne, land-based or sea-based type. Similarly, the communications station 14 is shown as a non-moving, terrestrial based communications station located on the Earth 16, and may be thought of as a "base"

landing. In today's environment, a typical system would include at least a pilot, perhaps a pre-flight technician, a mission controller, and a radar specialist for airspace deconfliction. In order to reduce the manual operations associated with a particular mission, more automation is needed at several levels.

Referring to FIG. 9, the three-dimensional (3D) synthetic vision system **80** can generate images depicting airspace and/or terrain in and around the operating aircraft **12** that include a "Highway-In-The-Sky" (HITS) visualization scheme to identify safe flight pathways and landing approaches. Where used with approaches, these are specifically designed to land the UAV **12** safely, taking in account surrounding terrain, obstacles and any other areas of concern.

Integrating Navigation and Actionable Intelligence

The primary purpose of the UAV **12** is to gather data, and the system **10** must translate this gathered data into actionable intelligence. Operators at the GCS **18**, however, must maintain control on both navigation and mission. The three-dimensional (3D) synthetic vision system **80** generates images of the type shown in FIG. 9 to integrate this information into a montage that permits the operators to conduct the mission while maintaining a high level of situational awareness. By way of example, FIG. 9 is a three-dimensional synthetic image showing the airspace and terrain in vicinity of craft **12**, along with a HITS display to landing (as discussed above), a projected landing zone **118**, a demarcation of a projected flight plan **120**, the location of an alarm **122** and an enhanced image of the corresponding anomaly **124**, and a video feed **126** from a region within the flight plan.

Such an image may be generated on displays coupled to GCS computer **17**, as well as being made available through a Remote Receiver Terminal that is receiving mission data via a SATCOM for use by field personnel. Alternatively, such a field computer can perform identical processing to that discussed above in connection ground station computer **17** in order to reconstruct, on its own, the complete situational imagery in real time.

Airborne Processor

In some embodiments, the aircraft-based elements shown in FIGS. 1-3 and discussed above are integrated into circuitry depicted in FIGS. 11-13 and discussed below. Referred to as "ACIP," this integrates in a "plug & play" fashion all the airborne electronics & associated functions typically found in small tactical UAV, e.g.:

1. Sensor payload (Camera, radar, IR etc)
2. Avionics (INS-GPS, autopilot, see & avoid etc.)
3. Data-links (telemetry, satcom etc.)
4. Flight management

The ACIP stands in contrast to prior art tactical UAV systems, which often have control and payload modules as separate entities that run in a non-integrated manner, which creates following problems:

1. Complicated control & command mechanism.
2. Inefficient usage of payload space, communication bandwidth and other critical resources on board the UAS
3. Non-scalable and inflexible configuration. Capacity increase or payload type change are not easy tasks and often result in total redesign of the payload configuration and control software.

On the other hand, while designers of some modern aircrafts like corporate jets and airliners have incorporated an integrated approach in their on board avionics system, the technologies used in those systems are not applicable in a tactic UAV due to the dramatic differences in terms of piloting method (manned vs. unmanned), on board resources (payload space, power, etc.)

ACIP is aimed to solve the paradox of not having enough on board resources, but the need to have more control and communication capability of the UAS. The ACIP is designed to be a highly autonomous navigation system with collision avoidance capability and INS/GPS based redundant autopilot function. Yet it also provide highly reliable communication links to the ground control station using multiple technologies such as satellite, broadband wireless (Wifi and WiMAX), and VHF Radio Control.

CONCLUSIONS

Described herein are systems and methods meeting the objects set forth above, among others. It will be appreciated, of course, that the embodiments discussed here are merely examples of the invention and that other embodiments, varying from those shown here fall within the scope of the invention. Thus, by way of non-limiting example, it will be appreciated that the video camera **38** and video processor **28** may form a single unit, such as in the case of a digital video camera. Moreover, it will be appreciated that the SATCOM links (though, of generally low-speed relative to other forms of communication) may support transmission speeds higher (or lower) than those mentioned above. In view of the foregoing, what we claim is:

The invention claimed is:

1. A system for unmanned vehicle operation, comprising
 - A. a control station,
 - B. a craft disposed remotely from the control station,
 - C. an image acquisition device coupled to the craft and arranged for generating one or more images of one or more scenes in a vicinity of the craft,
 - D. a first digital data processor coupled to the image acquisition device, the first digital processor identifying anomalies in one or more scenes in one or more images generated by the image acquisition device,
 - E. a second digital data processor disposed at the control station in communications coupling with the first digital data processor, the second digital data processor responding to signaling from the first digital data processor indicative of an anomaly by generating an image representative of a scene in which the anomaly was detected, and
 - F. wherein the first digital data processor is coupled with the second digital data processor by way of any of a low-bandwidth and/or small-antenna satellite link.
2. The system of claim 1, wherein the craft includes a dish antenna that supports communications comprising the satellite link.
3. The system of claim 2, wherein the dish antenna has a diameter of about 3 inches or less.
4. The system of claim 2, wherein the dish antenna has a diameter of about 5 inches or less.
5. The system of claim 2, wherein the dish antenna has a diameter of about 10 inches or less.
6. The system of claim 1, wherein the satellite link supports communications of about 9600 bps (bytes per second) or less.
7. The system of claim 1, wherein the image acquisition device is a video camera.
8. The system of claim 2, wherein the image acquisition device acquires video images of terrain, airspace, or other scenes in a vicinity of the craft.
9. The system of claim 1, wherein the first digital data processor is disposed on the craft.
10. The system of claim 1, wherein the second digital data processor is disposed at a distance that is beyond line of sight from the craft.

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11. A system for unmanned vehicle operation, comprising
- A. a control station,
 - B. a craft disposed remotely from the control station,
 - C. an image acquisition device coupled to the craft and arranged for generating one or more images of one or more scenes in a vicinity of the craft,
 - D. a first digital data processor coupled to the image acquisition device, the first digital processor identifying anomalies in one or more scenes in one or more images generated by the image acquisition device,
 - E. a second digital data processor disposed at the control station in communications coupling with the first digital data processor, the second digital data processor responding to signaling from the first digital data processor indicative of an anomaly by generating an image representative of a scene in which the anomaly was detected, and
 - F. wherein the image acquisition device is a video camera.
12. The system of claim 11, wherein the first digital data processor and the second digital data processor are coupled via any of a low-bandwidth and/or small-antenna satellite link.
13. The system of claim 12, wherein the craft includes a dish antenna that supports communications comprising the satellite link.
14. The system of claim 12, wherein the disk antenna has a diameter of about 3 inches or less.
15. The system of claim 11, wherein the satellite link supports communications of about 9600 bps (bytes per second) or less.
16. A digital data processor for use in remote surveillance, the digital data processor comprising
- A. a first subsystem in communications coupling with a remote craft including an image acquisition device, the first subsystem including logic that communicates command & control information with the craft,
 - B. a second subsystem in communications coupling with the first subsystem and with the craft via a satellite communications link, the second subsystem including logic that responds to signaling indicative of an anomaly in a vicinity of the craft by generating an image of scene including a location of that anomaly,
 - C. wherein the satellite communications link is any of a low-bandwidth and/or small-antenna satellite communications link.
17. The system of claim 16, wherein the disk antenna has a diameter of about 3 inches or less.
18. The system of claim 16, wherein the satellite link supports communications of about 9600 bps (bytes per second) or less.
19. The digital data processor of claim 16 further comprising a third subsystem in communications coupling with the second subsystem, the third subsystem storing images relayed from the craft and/or generated by the second subsystem.
20. The digital data processor of claim 16, wherein the second subsystem comprises a three-dimensional synthetic vision system that generates synthetic images of scenes within a vicinity of the craft that include the anomaly.
21. The digital data processor of claim 20, wherein the synthetic vision system generates synthetic images that highlight a location of the anomaly.
22. The digital data processor of claim 16, comprising any of a terrain, obstacle and/or navigational database.
23. A digital data processor for use on a surveillance aircraft, comprising

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- A. a video processor that is coupled to an image acquisition device disposed on the craft, the image acquisition device generating one or more images of one or more scenes in a vicinity of the craft,
 - B. a first digital data processor coupled to the image acquisition device, the first digital processor identifying anomalies in one or more scenes in one or more images generated by the image acquisition device,
 - C. where the image acquisition device is a video camera.
24. The digital data processor of claim 23, wherein the first digital processor utilizes an SSRX (subspace RX) methodology.
25. The digital data processor of claim 24, wherein the first digital processor applies the SSRX methodology to images generated by the video camera.
26. The digital data processor of claim 25, wherein the first digital processor applies the SSRX methodology to RGB color images generated by the video camera.
27. The digital data processor of claim 25, wherein the first digital processor applies the SSRX methodology to identify anomalies whose Mahalanobis distances correlate with actual or suspected alarm instances.
28. The digital data processor of claim 25, wherein the first digital processor performs spatial filtering on images resulting from application of the SSRX methodology.
29. The digital data processor of claim 28, wherein the first digital processor utilizes image pyramids to perform said spatial filtering.
30. The digital data processor of claim 28, wherein the first digital processor performs said spatial filtering in order to eliminate any of artifacts and objects of small width.
31. The digital data processor of claim 28, wherein the first digital data processor highlights an image generated from the video camera in accord with results of the spatial filtering.
32. A digital data processor for use on a surveillance aircraft, comprising a chassis having
- A. plug-and-play logic for sensor payload management,
 - B. plug-and-play logic for avionics,
 - C. plug-and-play logic for datalink management and communications,
 - D. plug-and-play logic for flight management.
33. The digital data processor of claim 32, comprising an embedded real-time operating system.
34. The digital data processor of claim 33, wherein the real-time operating system supports a master scheduler and one or more of a data flow manager, an emergency handler, a resource manager and a redundancy manager.
35. The digital data processor of claim 32, comprising a data channel manager that includes one or more of a connection manager and an encryption/decryption module, each of which is coupled to a data-link interface.
36. The digital data processor of claim 32, comprising a flight manager that includes one or more of a metadata generator, a traffic manager, a telemetry generator and a backup autopilot, each of which is coupled to an avionics interface.
37. The digital data processor of claim 32, comprising a data processor that executes one or more of a data fusion module, a data analysis module, a data compression module and a data conversion module, each of which is coupled to a sensor interface.
38. A system for unmanned vehicle operation, comprising
- A. a control station,
 - B. a craft disposed remotely from the control station,
 - C. an image acquisition device coupled to the craft and arranged for generating one or more images of one or more scenes in a vicinity of the craft,

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- D. a first digital data processor coupled to the image acquisition device, the first digital processor identifying anomalies in one or more scenes in one or more images generated by the image acquisition device,
- E. a second digital data processor disposed at the control station in communications coupling with the first digital data processor, the second digital data processor responding to signaling from the first digital data processor indicative of an anomaly by generating an image representative of a scene in which the anomaly was detected,
- F. wherein the first digital data processor is coupled with the second digital data processor by way of any of a low-bandwidth and/or small-antenna satellite link, and
- G. wherein the image acquisition device is a video camera.
- 39.** The system of claim **38**, wherein the first digital data processor utilizes an SSRX (subspace RX) methodology.
- 40.** The digital data processor of claim **39**, wherein the first digital processor applies the SSRX methodology to images generated by the video camera.
- 41.** The digital data processor of claim **40**, wherein the first digital processor applies the SSRX methodology to RGB color images generated by the video camera.
- 42.** The digital data processor of claim **40**, wherein the first digital processor applies the SSRX methodology to identify anomalies whose Mahalanobis distances correlate with actual or suspected alarm instances.
- 43.** The digital data processor of claim **40**, wherein the first digital processor performs spatial filtering on images resulting from application of the SSRX methodology.
- 44.** The digital data processor of claim **43**, wherein the first digital processor utilizes image pyramids to perform said spatial filtering.
- 45.** The digital data processor of claim **43**, wherein the first digital processor performs said spatial filtering in order to eliminate any of artifacts and objects of small width.
- 46.** The digital data processor of claim **43**, wherein the first digital data processor highlights an image generated from the video camera in accord with results of the spatial filtering.
- 47.** The system of claim **38**, wherein the second digital data processor comprises a first subsystem in communications coupling with a remote craft including an image acquisition device, the first subsystem including logic that communicates command & control information with the craft.
- 48.** The system of claim **39**, wherein the second digital data processor comprises a second subsystem in communications coupling with the first subsystem and with the craft via a

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- satellite communications link, the second subsystem including logic that responds to signaling indicative of an anomaly in a vicinity of the craft by generating an image of scene including a location of that anomaly.
- 49.** A method for unmanned vehicle operation, comprising
- A. generating, with an image acquisition device that is coupled to a craft, one or more images of one or more scenes in a vicinity of the craft,
- B. identifying, with a first digital data processor, anomalies in one or more scenes in one or more images generated by the image acquisition device,
- C. communicating between the first digital data processor and a second digital data processor by way of any of a low-bandwidth and/or small-antenna satellite link, and
- C. responding, with a second digital data processor that is disposed remotely from the first digital data processor, to signaling from the first digital data processor indicative of an anomaly by generating an image representative of a scene in which the anomaly was detected.
- 50.** The method of claim **49**, wherein the image acquisition device is a video camera.
- 51.** A method of operating a digital data processor for use in remote surveillance, the method comprising
- A. communicating between the digital data processor and a remote craft that has an on-board image acquisition device, wherein such communication is conducted over a low-bandwidth and/or small-antenna satellite communications link, and
- B. responding to signaling indicative received from the craft of an anomaly in a vicinity thereof by generating an image of scene including a location of that anomaly.
- 52.** The method of claim **51**, wherein the image acquisition device is a video camera.
- 53.** A method of operating a digital data processor that is disposed on a surveillance aircraft, comprising
- A. acquiring, from image acquisition device that is disposed on the aircraft, one or more images of one or more scenes in a vicinity of the craft,
- B. identifying, utilizing the digital data processor, anomalies in one or more scenes in one or more images generated by the image acquisition device, and
- C. where the image acquisition device is a video camera.
- 54.** The method of claim **53**, wherein step (B) includes executing an SSRX (subspace RX) algorithm on a video image received from the image acquisition device.

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