US009977117B2

(12) United States Patent
Parker et al.

(10) Patent No.: US 9,977,117 B2
(45) Date of Patent: May 22, 2018

(54) **SYSTEMS AND METHODS FOR DETECTING, TRACKING AND IDENTIFYING SMALL UNMANNED SYSTEMS SUCH AS DRONES**

(71) Applicant: **XiDrone Systems, Inc.**, Naples, FL (US)

(72) Inventors: **Dwaine A. Parker**, Naples, FL (US); **Damon E. Stern**, Riverview, FL (US); **Lawrence S. Pierce**, Huntsville, AL (US)

(73) Assignee: **XiDrone Systems, Inc.**, Naples, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days. days.

(21) Appl. No.: **15/598,112**

(22) Filed: **May 17, 2017**

(65) **Prior Publication Data**

US 2017/0248687 A1 Aug. 31, 2017

Related U.S. Application Data

(63) Continuation of application No. 14/821,907, filed on Aug. 10, 2015, now Pat. No. 9,689,976.

(Continued)

(51) **Int. Cl.**
G01S 7/38 (2006.01)
G01S 13/42 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01S 7/38*** (2013.01); ***F41H 11/02*** (2013.01); ***G01S 3/782*** (2013.01); ***G01S 7/414*** (2013.01); ***G01S 13/42*** (2013.01); ***G01S 13/88*** (2013.01)

(58) **Field of Classification Search**
CPC . G01S 7/021; G01S 7/38; G01S 7/414; G01S 13/42; G01S 13/52; G01S 13/5244;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,668,403 A * 6/1972 Meilander G01S 13/9303 342/36
3,754,249 A * 8/1973 Kearney, II F41G 7/007 244/3.13

(Continued)

OTHER PUBLICATIONS

Interntional Preliminary Report on Patentability and Written Opinion of the International Searching Authority dated Jun. 29, 2017, issued in related International Application No. PCT/US2015/059698.

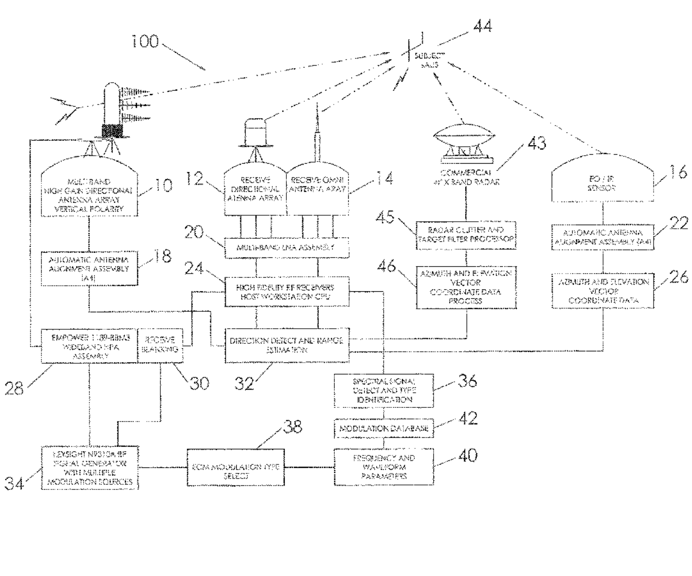
(Continued)

Primary Examiner — Peter M Bythrow
(74) *Attorney, Agent, or Firm* — Nixon & Vanderhye P.C.

(57) **ABSTRACT**

A system for providing integrated detection and countermeasures against unmanned aerial vehicles include a detecting element, a location determining element and an interdiction element. The detecting element detects an unmanned aerial vehicle in flight in the region of, or approaching, a property, place, event or very important person. The location determining element determines the exact location of the unmanned aerial vehicle. The interdiction element can either direct the unmanned aerial vehicle away from the property, place, event or very important person in a non-destructive manner, or can cause disable the unmanned aerial vehicle in a destructive manner.

23 Claims, 4 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/094,154, filed on Dec. 19, 2014.

(51) **Int. Cl.**
F41H 11/02 (2006.01)
G01S 7/41 (2006.01)
G01S 3/782 (2006.01)
G01S 13/88 (2006.01)

(58) **Field of Classification Search**
CPC G01S 13/86; G01S 13/865; G01S 13/867; G01S 13/88; G01S 13/883; G01S 13/9303; G01S 13/91; G01S 13/93; F41H 11/00; F41H 11/02; F41H 13/0043; F41H 13/0075
USPC 342/13
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,981,010 A * 9/1976 Michelsen F41G 3/2611 342/125
4,652,885 A * 3/1987 Saffold H01Q 5/45 342/53
4,698,638 A * 10/1987 Branigan F41G 7/008 342/53
4,780,719 A * 10/1988 Frei G01S 13/86 342/351
5,005,147 A * 4/1991 Krishen G06K 9/6293 703/13
5,268,680 A * 12/1993 Zantos F41G 7/008 342/53
5,307,077 A * 4/1994 Branigan G01S 13/4463 342/53
5,327,149 A * 7/1994 Kuffer G01S 13/86 342/53
5,341,142 A * 8/1994 Reis F41G 7/2226 244/3.15
5,381,150 A * 1/1995 Hawkins G01R 23/165 342/13
5,402,129 A * 3/1995 Gellner G01S 13/348 342/70
5,554,990 A * 9/1996 McKinney G01S 7/22 342/176
5,557,278 A * 9/1996 Piccirillo G01S 7/003 342/29
5,728,965 A * 3/1998 Fesland B64C 39/024 244/190
6,081,764 A * 6/2000 Varon G01S 13/91 342/29
6,087,974 A * 7/2000 Yu F41G 7/2226 244/3.1
6,262,679 B1 * 7/2001 Tran G01S 13/9303 342/29
6,529,820 B2 * 3/2003 Tomescu G01S 5/0063 342/36
6,563,453 B1 * 5/2003 Wilson G01S 13/782 342/29
6,564,149 B2 * 5/2003 Lai G01S 7/06 340/945
6,690,296 B2 * 2/2004 Corwin G01S 13/782 340/945
6,707,052 B1 * 3/2004 Wild .... F41H 11/02 250/504 R
6,877,691 B2 * 4/2005 DeFlumere G01S 7/4802 244/3.1
6,903,676 B1 * 6/2005 Frady F41H 11/00 342/52
7,202,809 B1 * 4/2007 Schade F41A 1/08 244/3.1
7,205,932 B2 * 4/2007 Fiore G01S 13/32 342/104
7,437,225 B1 * 10/2008 Rathinam G08G 5/0013 340/961
7,492,308 B2 * 2/2009 Benayahu F41H 7/00 244/3.1
7,504,982 B2 * 3/2009 Berg F41G 5/08 342/13
7,548,184 B2 * 6/2009 Lo F41G 7/008 244/3.15
7,551,121 B1 * 6/2009 O'Connell F41G 5/08 235/400
7,619,555 B2 * 11/2009 Rolfe H04B 7/18506 342/29
7,782,256 B2 * 8/2010 Smith G01S 5/06 342/453
7,898,454 B1 * 3/2011 Starkey G01S 7/38 342/14
7,961,133 B2 * 6/2011 Vollin F41G 7/224 342/14
8,212,709 B2 * 7/2012 Bradley F41G 7/224 244/3.1
8,258,994 B2 * 9/2012 Hamilton F41G 7/224 244/3.1
8,258,998 B2 * 9/2012 Factor G01S 7/36 342/12
8,330,641 B2 * 12/2012 Ryden H04K 3/45 342/14
8,378,880 B1 * 2/2013 Boka G01S 13/726 244/3.1
8,378,881 B2 * 2/2013 LeMire G01S 13/87 342/59
8,464,949 B2 * 6/2013 Namey F41H 5/007 235/404
8,543,265 B2 * 9/2013 Ekhaguere G05D 1/101 701/11
9,041,798 B1 * 5/2015 Yerkes G06K 9/00771 340/10.1
9,170,069 B1 * 10/2015 Smith G01S 7/495
9,175,934 B1 * 11/2015 Kilian F41H 13/00
9,212,869 B1 * 12/2015 Boardman G01S 13/726
9,405,005 B1 * 8/2016 Arteaga G01S 13/91
9,495,877 B2 * 11/2016 Duffy G08G 5/0013
9,508,264 B2 * 11/2016 Chan G08G 5/0043
2004/0021852 A1 * 2/2004 DeFlumere F41G 7/008 356/141.1
2004/0249519 A1 * 12/2004 Frink B64D 45/0015 701/3
2006/0028373 A1 * 2/2006 Fullerton F41H 11/00 342/67
2006/0028374 A1 * 2/2006 Fullerton F41G 5/08 342/67
2006/0092075 A1 * 5/2006 Bruce G01S 7/02 342/175
2006/0106506 A1 * 5/2006 Nichols G05D 1/101 701/3
2006/0175464 A1 * 8/2006 Chang F41H 5/007 244/3.19
2007/0052580 A1 * 3/2007 Fiore G01S 13/32 342/133
2008/0018519 A1 * 1/2008 Berg F41G 5/08 342/14
2008/0088508 A1 * 4/2008 Smith G01S 5/06 342/453
2009/0292468 A1 * 11/2009 Wu G01S 13/726 701/301
2010/0042269 A1 * 2/2010 Kokkeby G01S 3/7864 701/3
2010/0315281 A1 * 12/2010 Askelson G01S 7/003 342/30
2012/0143482 A1 * 6/2012 Goossen G08G 5/0034 701/120
2012/0217301 A1 * 8/2012 Namey F41H 5/007 235/411
2014/0102288 A1 * 4/2014 Yeshurun F41H 5/007 89/36.17

(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0138474	A1*	5/2014	Sharpin	F41H 11/02 244/3.22
2014/0200875	A1*	7/2014	Yuksel Ergun	F41G 3/04 703/21
2014/0251123	A1*	9/2014	Venema	F41G 3/16 89/41.22
2014/0266851	A1*	9/2014	Fink	G01S 7/36 342/14
2015/0254988	A1*	9/2015	Wang	G05D 1/0214 701/3
2016/0117931	A1*	4/2016	Chan	G08G 5/0043 701/120
2016/0358483	A1*	12/2016	Park	G01S 19/01

OTHER PUBLICATIONS

N9310A RF Signal Generator, 9kHz to 3 GHz, Key Features & Specifications, Keysight Technologies (1994), retrieved Nov. 14, 2017, 2 pages.
RF Power Amplifiers, High Power—6GHz and below, Empower RF Systems, Inc. (1994), retrieved Nov. 14, 2017, 1 page.
Smart Sensor Radar System, Vista Radar Systems (1994), Raven Aerostar, Product Overview, retrieved Nov. 14, 2017, 2 pages.
WiNRADiO MS-8118/G3 Multichannel Radio Monitoring System (1994), Product Overview, retrieved Nov. 14, 2017, 2 pages.
WiNRADiO WD-3300 High Performance Portable Direction Finding System (1994), Product Overview, retrieved Nov. 14, 2017, 2 pages.

* cited by examiner

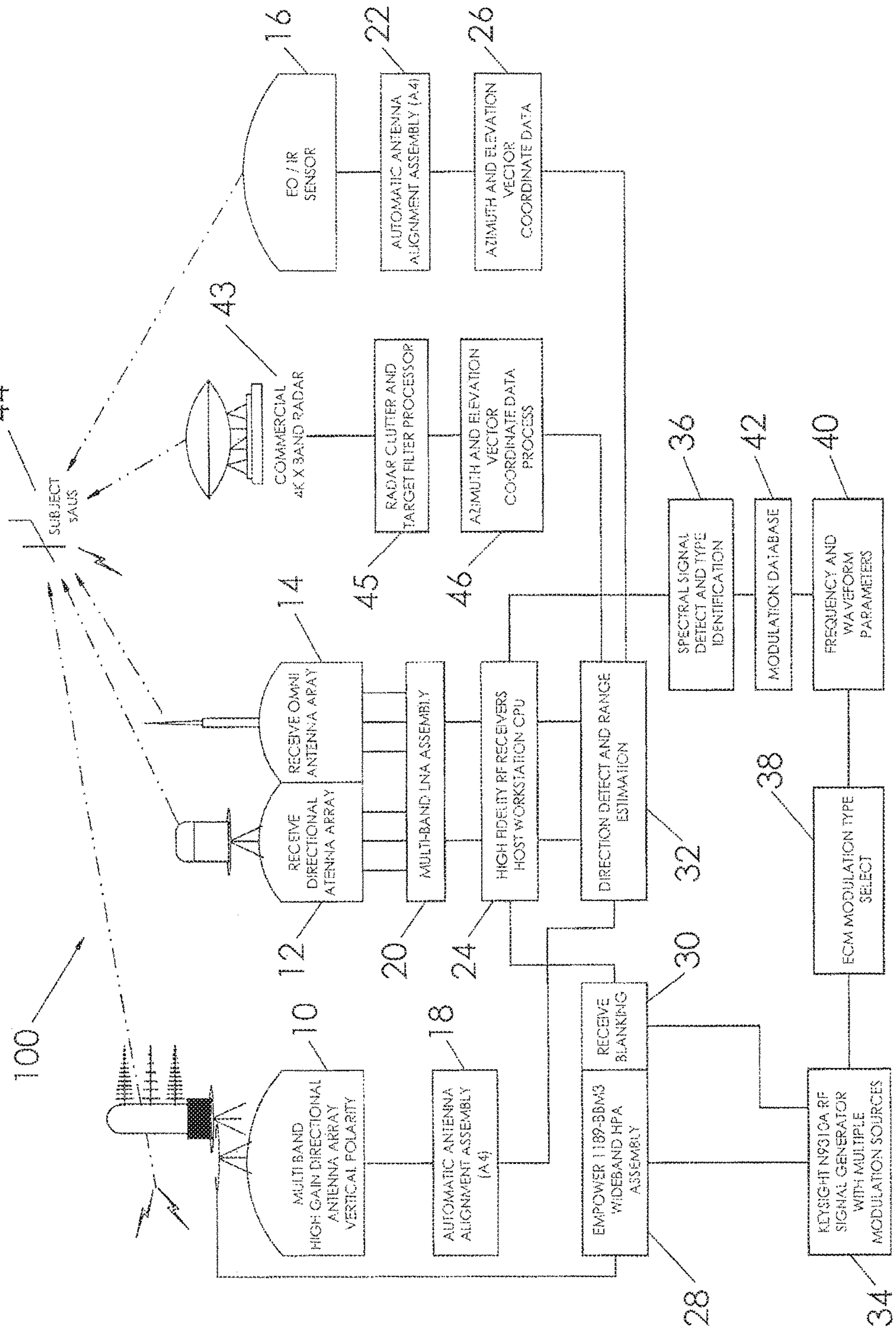

100
10
MULTI BAND HIGH GAIN DIRECTIONAL ANTENNA ARRAY VERTICAL POLARITY
18
AUTOMATIC ANTENNA ALIGNMENT ASSEMBLY (A4)
28
EMPOWER 1189-BBM3 WIDEBAND HPA ASSEMBLY
30
RECEIVE BLANKING
34
KEYSIGHT N9310A RF SIGNAL GENERATOR WITH MULTIPLE MODULATION SOURCES
12
RECEIVE DIRECTIONAL ATENNA ARRAY
14
RECEIVE OMNI ANTENNA ARAY
20
MULTI-BAND LNA ASSEMBLY
24
HIGH FIDELITY RF RECEIVERS HOST WORKSTATION CPU
32
DIRECTION DETECT AND RANGE ESTIMATION
38
ECM MODULATION TYPE SELECT
44
SUBJECT sAUS
43
COMMERCIAL 4K X BAND RADAR
45
RADAR CLUTTER AND TARGET FILTER PROCESSOR
46
AZIMUTH AND ELEVATION VECTOR COORDINATE DATA PROCESS
36
SPECTRAL SIGNAL DETECT AND TYPE IDENTIFICATION
42
MODULATION DATABASE
40
FREQUENCY AND WAVEFORM PARAMETERS
16
EO / IR SENSOR
22
AUTOMATIC ANTENNA ALIGNMENT ASSEMBLY (A4)
26
AZIMUTH AND ELEVATION VECTOR COORDINATE DATA

FIGURE 1

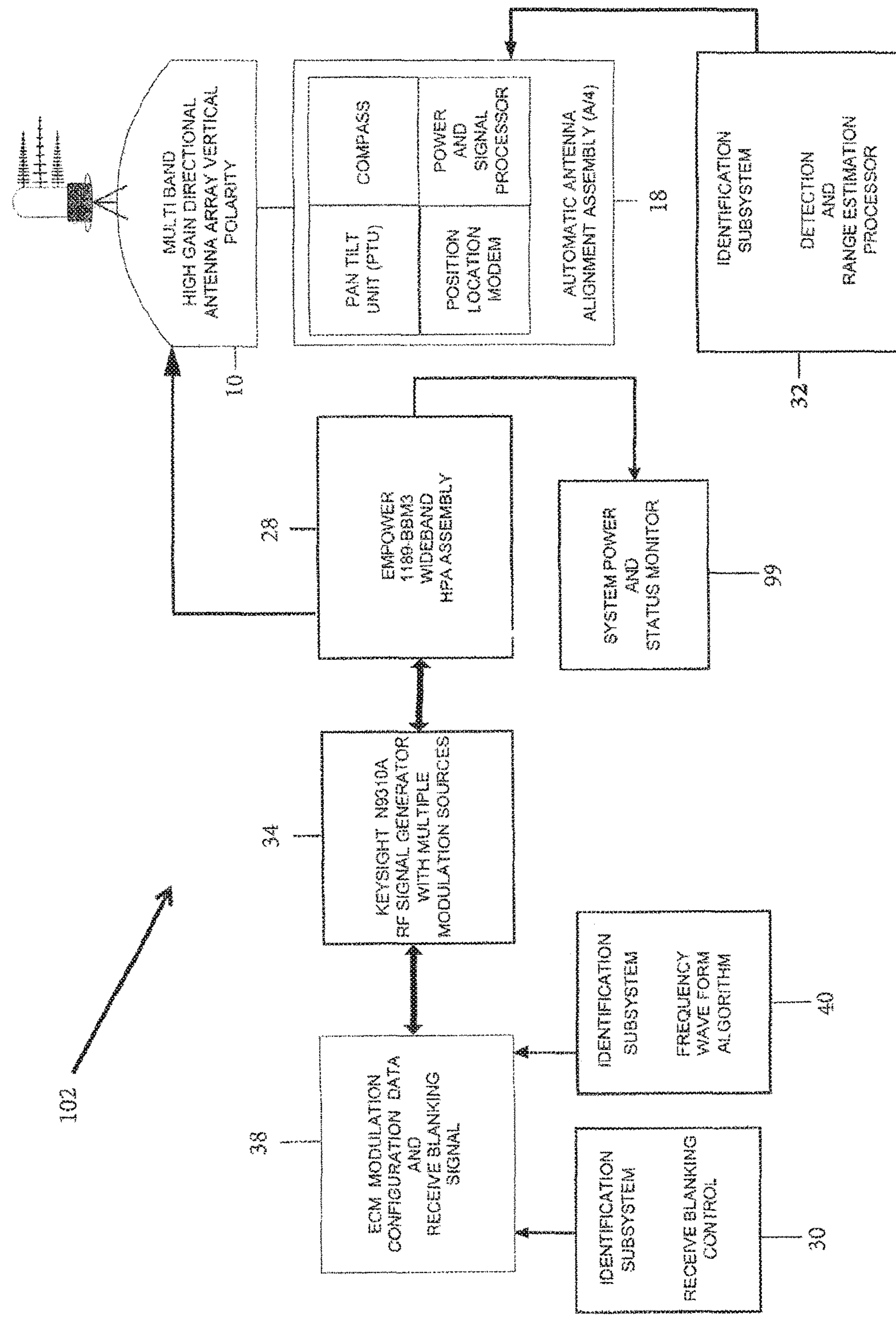

MULTI BAND HIGH GAIN DIRECTIONAL ANTENNA ARRAY VERTICAL POLARITY
10
PAN TILT UNIT (PTU)
COMPASS
POSITION LOCATION MODEM
POWER AND SIGNAL PROCESSOR
AUTOMATIC ANTENNA ALIGNMENT ASSEMBLY (A/4)
18
IDENTIFICATION SUBSYSTEM
DETECTION AND RANGE ESTIMATION PROCESSOR
32
28
EMPOWER 1189-BBM3 WIDEBAND HPA ASSEMBLY
SYSTEM POWER AND STATUS MONITOR
99
34
KEYSIGHT N9310A RF SIGNAL GENERATOR WITH MULTIPLE MODULATION SOURCES
102
38
ECM MODULATION CONFIGURATION DATA AND RECEIVE BLANKING SIGNAL
IDENTIFICATION SUBSYSTEM
FREQUENCY WAVE FORM ALGORITHM
40
IDENTIFICATION SUBSYSTEM
RECEIVE BLANKING CONTROL
30

FIGURE 2

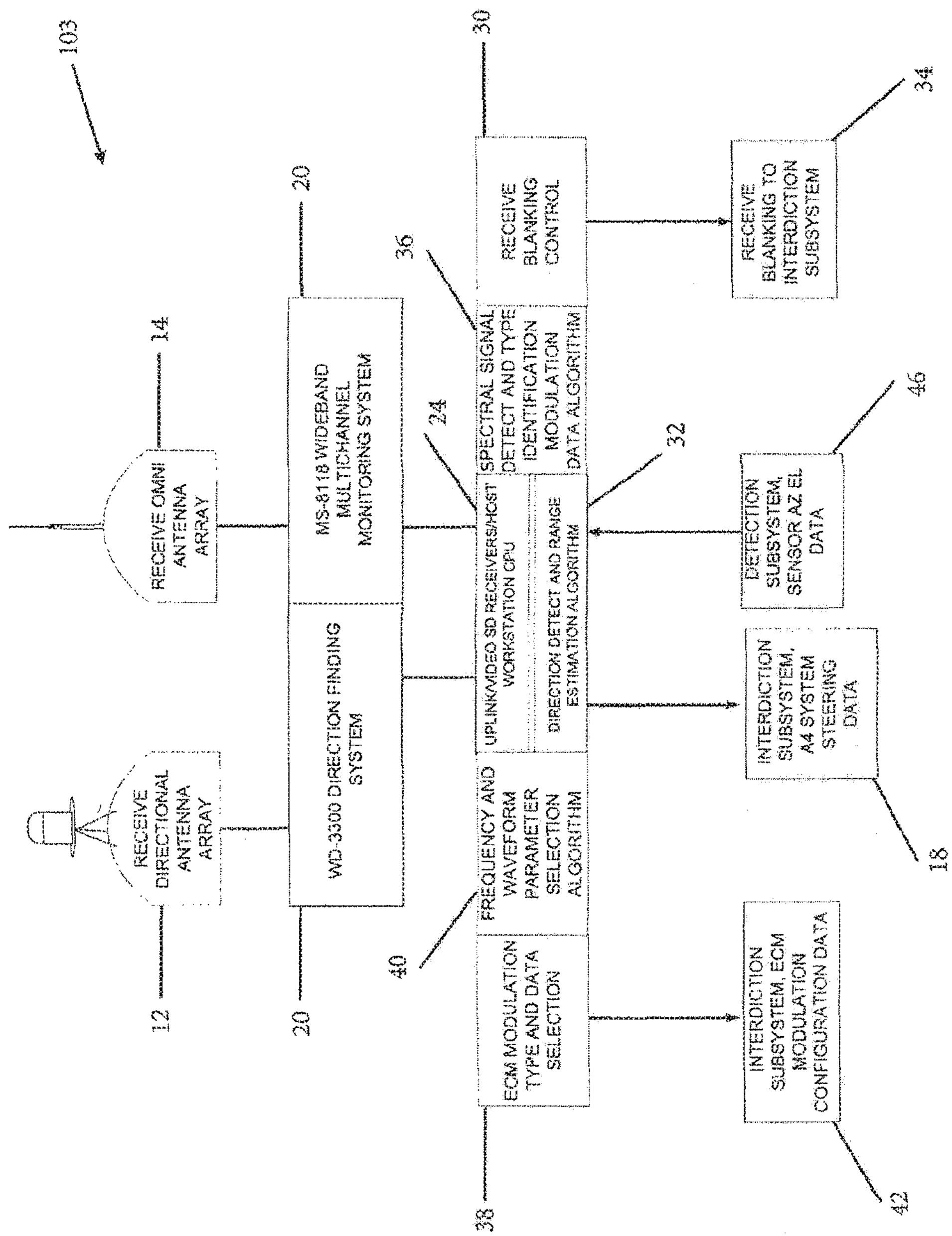

103
RECEIVE DIRECTIONAL ANTENNA ARRAY
12
RECEIVE OMNI ANTENNA ARRAY
14
WD-3300 DIRECTION FINDING SYSTEM
MS-8118 WIDEBAND MULTICHANNEL MONITORING SYSTEM
20
20
UPLINK/VIDEO SD RECEIVERS/HOST WORKSTATION CPU
DIRECTION DETECT AND RANGE ESTIMATION ALGORITHM
24
32
SPECTRAL SIGNAL DETECT AND TYPE IDENTIFICATION MODULATION DATA ALGORITHM
36
RECEIVE BLANKING CONTROL
30
FREQUENCY AND WAVEFORM PARAMETER SELECTION ALGORITHM
40
ECM MODULATION TYPE AND DATA SELECTION
38
RECEIVE BLANKING TO INTERDICTION SUBSYSTEM
34
DETECTION SUBSYSTEM, SENSOR AZ EL DATA
46
INTERDICTION SUBSYSTEM, AZ SYSTEM STEERING DATA
18
INTERDICTION SUBSYSTEM, ECM MODULATION CONFIGURATION DATA
42

FIGURE 3

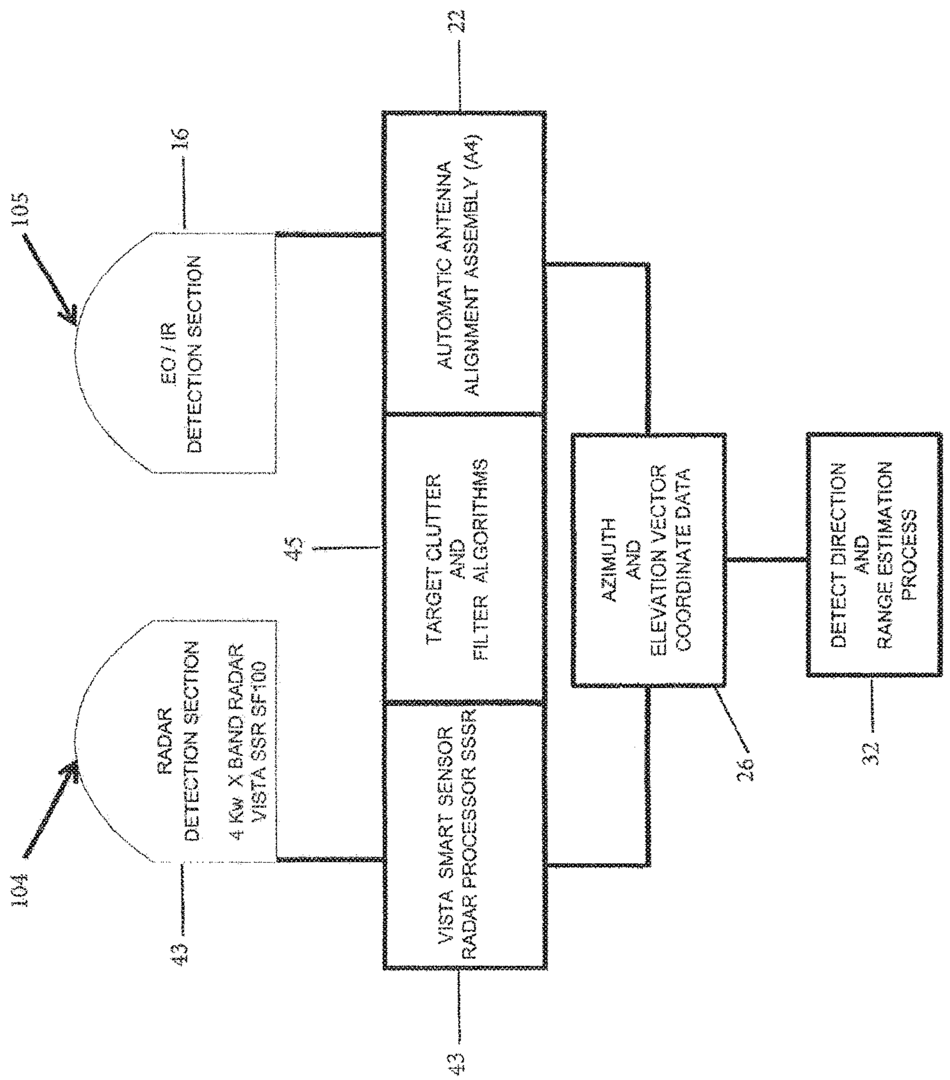

105
16
EO / IR
DETECTION SECTION
22
AUTOMATIC ANTENNA
ALIGNMENT ASSEMBLY (A4)
104
43
RADAR
DETECTION SECTION
4 Kw X BAND RADAR
VISTA SSR SF100
45
TARGET CLUTTER
AND
FILTER ALGORITHMS
AZIMUTH
AND
ELEVATION VECTOR
COORDINATE DATA
26
DETECT DIRECTION
AND
RANGE ESTIMATION
PROCESS
32
VISTA SMART SENSOR
RADAR PROCESSOR SSSR
43

FIGURE 4

SYSTEMS AND METHODS FOR DETECTING, TRACKING AND IDENTIFYING SMALL UNMANNED SYSTEMS SUCH AS DRONES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/821,907 filed Aug. 10, 2015; which claims the benefit of U.S. Provisional Application No. 62/094,154 filed Dec. 19, 2014. The disclosures of the prior applications are incorporated herein in their entirety by reference.

FIELD OF THE INVENTION

The present invention relates to an integrated detection and countermeasure solution against unmanned aerial systems, which are commonly referred to as drones.

BACKGROUND OF THE INVENTION

Unmanned aerial systems, which are commonly referred to as drones, have become commercially available to the general public. While there may be many safe commercial and recreational uses for unmanned aerial systems these devices may potentially pose hazards to commercial and general aviation, the public, and private and government property if improperly operated. Furthermore unmanned aerial systems may be used to violate the privacy of personal, commercial, educational, athletic, entertainment and governmental activities. Most unfortunately unmanned aerial systems may potentially be used in the furtherance of invading privacy, or carrying out terrorist and/or criminal activities. There is a need for a device and method of detecting the approach of an unmanned aerial system towards a location where personal, public, commercial, educational, athletic, entertainment and governmental activities occur and where an unmanned aerial system could potentially be used for invading privacy, or carrying out terrorist and criminal activities. The present invention provides an integrated detection and countermeasure solution against unmanned aerial systems and offers increased security, privacy, and protection from the threats of violence involving small unmanned aerial vehicles/systems (sUAS) and is applicable to governmental, commercial, private, and public concerns.

SUMMARY OF THE INVENTION

There is provided in accordance with the present invention a system that detects, identifies, tracks, deters and or interdicts small unmanned aerial vehicles/systems (sUAS) from ground level to several thousand feet above ground level. The system disclosed herein is an integrated solution comprising components using: existing technology for a new use; multiplexing hardware components designed for this application; and development of the integrating software which calculates the exact x, y, z coordinates of the subject sUAS; subject sUAS RF signal analysis to determine the most appropriate RF signal characteristics to affect the subject sUAS; precision alignment of high definition electro-optical (EO) sensors and infrared (IR) sensors and image recognition algorithms providing confirmation that the subject sUAS is in violation of airspace authorization. The integration of these components via the herein disclosed combination of software and hardware is novel, not related to existing art in purpose, is non-obvious, and provides a useful solution to uninvited, invasive and potentially hazardous sUAS operations.

The system of the present invention provides an integrated and diversified solution that can be deployed as a "permanent placement" or mobile system on land, sea, or air platform.

The system of the invention may be strategically deployed to monitor the airspace around a protected interest such as a property, place, event or very important person (VIP) offering 360 degree azimuth coverage extending from the receiving antennae of the system out to a maximum lateral distance of about 2 kilometers (6560 feet) and within the lateral boundaries up to a maximum altitude of about 1.5 kilometers (4920 feet) above ground level (AGL).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of the components and function of an integrated detection and countermeasure system for use against unmanned aerial systems.

FIG. **2** is a schematic representation of a countermeasure and interdiction to UAS system of the integrated detection and countermeasure system for use against unmanned aerial systems, **44** of FIG. **1**.

FIG. **3** is a schematic representation of the Radio Frequency (RF) detection system of the integrated detection and countermeasure system for use against unmanned aerial systems, **44** of FIG. **1**.

FIG. **4** is a schematic representation of the Radar detection system and Electro Optical and Infer Red (EO/IR) detection system of the integrated detection and countermeasure system for use against unmanned aerial systems, **44** of FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

Part Numbers

10 Transmitting multi band high gain directional antenna array with vertical polarity
12 Receive directional antenna array
14 Receive Omni antenna array
16 EO/IR (Electro Optical/Infra Red) sensor
18 Automatic antenna alignment assembly
20 Multi-band LNA assembly
22 Automatic antenna alignment assembly
24 High fidelity RF receivers/host work station CPU
26 Azimuth and elevation vector coordinate data processor
28 Empower 1189-BBM3 wideband HPA assembly
30 Receive blanking
32 Direction detect and range estimation
34 Key sight N9310A RF signal generator with multiple modulation sources
36 Spectral signals detect and type identification
38 ECM modulation type select
40 Frequency and waveform parameters
42 Modulation database
43 Commercial **4***k* X band radar
44 Subject UAS (Unmanned Aerial System)
45 Radar clutter and target filter processor
46 Azimuth and elevation vector coordinate data processor
99 System power and status monitor
100 Entire system

102 Countermeasure and deterrent section of entire system

103 Radio Frequency (RF) detection section of entire system

104 Radar detection section of entire system

105 Electro Optical and Infer Red (EO/IR) detection section of entire system

Glossary

As used herein and in the claims each of the terms defined in this glossary is understood to have the meaning set forth in this glossary.

Algorithm—a process or set of rules to be followed in calculations or other problem-solving operations by a computer

Automatic Antenna Alignment Assembly—designated as **18** in FIGS. **1**, **2** and **3**, and as **22** in FIGS. **1** and **4**, is specialized electronic equipment specifically designed to automatically point the directional antennae and or camera, laser systems to the desired location, namely a small unmanned aerial vehicles/systems (sUAS) designated as a target **44** in FIG. **1**, based on longitude and or latitude information gained or received by the receiving antennae, designated as **12** and **14** in FIGS. **1** and **3**, and or radar antennae designated as **43** in FIGS. **1** and **4**; this specialized equipment can be purchased from and is proprietary to EnrGies Engineering located in Huntsville, Ala.

Azimuth and Elevation Vector Coordinate Data—designated as **26** in FIGS. **1** and **4**, is specialized algorithm software that has been developed to be used with a spherical coordinate system for three-dimensional space where three numbers specify the position of a point measured in latitude, longitude and elevation obtained from an EO/IR Sensor designated as **16** in FIGS. **1** and **4** that includes a Laser Range Finder, and/or Radar designated as **43** in FIGS. **1** and **4**

Blanking—designated as **30** in FIGS. **1**, **2** and **3** is the time between the last radio transmitting signal and the beginning of the next radio transmitting signal

C2 Communications—Command and Control Communications links

Commercial—relating to or engaged in commerce (i.e. NON-military)

Counter—to offer in response or act in opposition

CUASs2—Counter Unmanned Aerial Systems of Systems, the system of the present invention used to detect, identify and deter or interdict unmanned aerial vehicles or systems

Directional Antenna—designated as **10** in FIGS. **1** and **2**, and **12** in FIGS. **1** and **3**, a class of directional or beam antenna that radiates greater power in one or more directions allowing for increased performance on transmits and receives and reduced interference from unwanted sources

Direction Detection and Range Estimation—designated as **32** in FIGS. **1**-**4**, is specialized algorithm software that has been developed to detect a suspected target or signal of interest and calculated to obtain the azimuth and distance to that target or signal of interest based on data obtained by the Radio Frequency (RF) detection section **103** in FIG. **3**, the Radar detection section **104** in FIG. **4**, and the Electro Optical and Infer Red (EO/IR) detection section **105** in FIG. **4**

DF—designated as **12** in FIGS. **1** and **3**, Direction Finding refers to the measurement of the direction from which a received signal was transmitted, this can refer to radio or other forms of wireless communication

Drone—designated as **44** in FIG. **1**, refers to an unmanned aircraft operated by remote control, allows for human correction (i.e. semi-autonomous), or autonomous, see also UAV, UAS, sUAS, RPA

EAR—Export Administration Regulations are regulations that are administered by the United States Department of Commerce and regulate the export of "dual use" items; technology designed for commercial purposes and with potential military applications, such as computers, software, aircraft, and pathogens as well the re-export of items

Electro-Optical and Infrared Sensors—designated as **16** in FIGS. **1** and **4**, is a combination of a standard high definition video camera capable of viewing in daylight conditions and an infrared video camera capable of viewing in the infrared light perspective; both camera systems can be purchased "Off-The-Shelf" as common technology, one common manufacturer of this type of camera systems is FLIR Systems

Electronic Counter Measure (ECM) Modulation Type Select—designated as **38** in FIGS. **1**-**3** is specialized algorithm software that has been developed to help narrow down the radio frequency identified by a modulation lookup table (defined in this glossary) of the specific unmanned aerial vehicle/system of interest, designated as a target **44** in FIG. **1**, utilizing a database library that was created and categorized with the specific radio frequencies common to all unmanned aerial vehicles/systems

Emitter—to send or give out a matter of energy

EO—Electro-Optics is a branch of electrical engineering and materials science involving components, devices and systems that operate by modification of the optical properties of a material by an electric field, thus it concerns the interaction between the electromagnetic (optical) and the electrical (electronic) states of materials

Frequency—the rate at which a vibration occurs that constitutes a wave, either in a material (as in sound waves), or in an electromagnetic field (as in radio waves and light), usually measured per second

Frequency and Waveform Parameters—designated as **40** in FIGS. **1**-**3**, Is specialized algorithm software that has been developed to identify unmanned aerial vehicles/systems utilizing a database library that was created and categorized with the specific radio frequency waveform common to all unmanned aerial vehicles/systems

IR—infrared is invisible (to the human eye) radiant energy, electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (frequency 430 THz) to 1 mm (300 GHz)

ISR—Intelligence, Surveillance, Reconnaissance is an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations

ITAR—International Traffic in Arms Regulations is a set of United States government regulations that control the export and import of defense-related articles and services on the United States Munitions List (USML)

Jam or Jammed or Jammers or Jamming—to interfere with or prevent the clear reception of broadcast signals by electronic means to become unworkable or to make unintelligible by sending out interfering signals by any means

Laser—a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation

Laser Range Finder—designated as **16** in FIGS. **1** and **4**, is a rangefinder which uses a laser beam, usually pulsed, to determine the distance to an object

LED—Light-Emitting Diode is a semiconductor device that emits visible light when an electric current passes through it

Matrix—an environment in which something develops

Matrix Directional Transmit Antenna Array—designated as **10** in FIGS. **1** and **2**, Is a signal processing technique used in sensor (Antenna) arrays for directional signal transmission; this is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference; his equipment can be purchased "Off-The-Shelf" and one common manufacturer of this type of equipment is Motorola

Mobile Platform (MP)—the mobile Counter Unmanned Aerial System of Systems equipment installed on any vehicle with the intent to move from one location to another location as needed to fulfill a short-term need in the detection, identification and deterrence or interdiction of an unmanned aerial vehicle

Modulation—the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted

Modulation Function Generation—designated as **34** in FIGS. **1**-**3**, Is specialized algorithm software that has been developed to transmit (Jam) a specific radio frequency, designated by **38** in FIGS. **1**-**3** and **42** in FIGS. **1** and **3**, which is unique to a specific unmanned aerial vehicles/systems utilizing a database library that was created and categorized with the specific radio frequencies used on all common unmanned aerial vehicles/systems

Modulation Lookup Table—designated as **42** in FIGS. **1** and **3**, is specialized algorithm software that has been developed to identify the broad range of radio frequencies being used by a specific unmanned aerial vehicle/system of interest, designated as a target **44** in FIG. **1**, utilizing a database library that was created and categorized with the specific radio frequencies common to all unmanned aerial vehicles/systems

Multi-Band—a communication device that supports multiple radio frequency bands

Multiband Low Noise Amplifier (LNA) Assembly—designated as **20** in FIGS. **1** and **3**, is a multi-radio frequency electronic amplifier used to amplify possibly very weak signals, for example captured by an antenna

Omni-directional Antenna—designated as **14** in FIGS. **1** and **3**, a class of antenna which receives or transmits radio wave power uniformly in all directions in one plane, with the radiated power decreasing with elevation angle above or below the plane, dropping to zero on the antenna's axis

OTS—Off The Shelf refers to materials or equipment that currently exists and is readily available for purchased or use

Permanent Platform (PP)—the installation of the Counter Unmanned Aerial System of Systems equipment at a specific location to fulfill a long-term need in the detection, identification and deterrence or interdiction of an unmanned aerial vehicle

Pulse—a single vibration or short burstof sound, electric current, light, or other wave

RPA—Remotely Piloted Aircraft, aka UAV, UAS

RF—Radio Frequency is a rate of oscillation in the range of around 3 kHz to 300 GHz, which corresponds to the frequency of radio waves, and the alternating currents that carry radio signals

Receive Blanking—designated as **30** in FIGS. **1**-**3**, is specialized algorithm software that has been developed to stop the receiving antennae, designated as **12** and **14** in FIGS. **1** and **3**, from receiving radio frequency signals during the time that the counter measure transmitting frequency, designated as **34** in FIGS. **1**-**3**, is being transmitted by directional transmitting antennae, designated as **10** in FIGS. **1** and **2**, for the purpose of deterrence or interdiction of the suspect unmanned aerial vehicle/system, designated as a target **44** in FIG. **1**, identified as a known threat

Receive Directional Antenna Array—designated as **12** in FIGS. **1** and **3**, refers to multiple receiving antennae arranged such that the superposition of the electromagnetic waves is a predictable electromagnetic field and that the currents running through them are of different amplitudes and phases; this equipment can be purchased "Off-The-Shelf" and one common manufacturer of this type of equipment is Motorola

Receive Omni Antenna Array—designated as **14** in FIGS. **1** and **3**, is a class of antenna that receives radio wave power uniformly in all directions in one plane; this equipment can be purchased "Off-The-Shelf" and one common manufacturer of this type of equipment is Motorola

STC—Slew To Cue, the autonomous actions of electronic, radio or optical sensors to rotate using an automatic antenna alignment assembly designated as **18** in FIGS. **1**-**3**, and **22** in FIGS. **1** and **4** to move and point cameras **16** in FIGS. **1** and **4** and countermeasures **10** in FIGS. **1** and **2** in the direction of a suspect target **44** in FIG. **1**, based on input from data processed by components **26** in FIGS. **1** and **4**, and **46** in FIGS. **1**, **3** and **4**, thus, keeping the "cued" targets in view at all times with or without human intervention

Spectral Signal—designated as **36** in FIGS. **1** and **3**, the frequency spectrum of a time-domain signal is a representation of that signal in the frequency domain

Spectral Signal Detection and Type Identification—designated as **36** in FIGS. **1** and **3**, is specialized algorithm software that has been developed to detect and identify unmanned aerial vehicles/systems utilizing a database library that was created and categorized with the spectral signatures common to all unmanned aerial vehicles/systems

sUAS—designated as **44** in FIG. **1** small Unmanned Aerial System, usually weighing less than 20 kg or 55 lbs.

Target—designated as **44** in FIG. **1**, something or someone of interest to be affected by an action or development

Target Tracking Log—a graphic or table of coordinates documenting the target's path in space during area of concern

Technology—the application of science, especially to industrial or commercial objectives

Threat—a declaration or an act of an intention or determination to inflict the destruction of property or harm, punishment, injury or death of person(s)

UAS—designated as **44** in FIG. **1**, Unmanned Aerial System, Unmanned Aircraft System (aka UAV, RPA)

UAV—designated as **44** in FIG. **1**, Unmanned Aerial Vehicle, Unmanned Aircraft Vehicle (aka UAS, RPA)

Uplink—the part of a network connection used to send, or upload, data from one device to a remote device

Uplink Video/Radio Transmitter Assembly—designated as **28** in FIGS. **1** and **2**, is a device that will take the received radio or video frequency information from database libraries designated as **36** in FIGS. **1** and **3**, **40** in FIGS. **1**-**3**, and **42** in FIGS. **1** and **3** and send it through a radio amplifier designated as **34** in FIGS. **1**-**3** to a transmitting directional antenna or matrix directional transmit antenna array designated as **10** in FIGS. **1** and **2**; this equipment can be purchased "Off-The-Shelf" and one common manufacturer of this type of equipment is Motorola

Uplink/Video Standard Definition (SD) Receiver & Host Workstation—designated as **24** in FIGS. **1** and **3**, is a connection from the antennae to the video encoder where the information is processed by the main computer network; the uplink equipment can be purchased "Off-The-Shelf" and one common manufacturer of this type of equipment is Cisco Systems; the video receiver and main computer is also "Off-The-Shelf" technology and are readily available from numerous manufacturers

Vector—a quantity having direction as well as magnitude, especially as determining the position of one point in space relative to another

Watt—the system unit of power, equivalent to one joule per second, corresponding to the power in an electric circuit in which the potential difference is one volt and the current one ampere

Waveform—a graphic representation of the shape of a wave that indicates its characteristics as frequency and amplitude

Referring to FIGS. **1-4** there are shown schematic representations of the components and function of an integrated detection and countermeasure system **100** for use against unmanned aerial systems **44**. A first function of the system is locating and identifying a UAS target. The present invention provides integrated detection sections **103-105** and deterrent/countermeasure section **102** against small unmanned aerial vehicles/systems (sUAS), which are commonly referred to as drones, in the vicinity of, or approaching the vicinity of a property, place, event or very important person (VIP). All sUAS's have a distinct set of spectral signatures (sound, heat, radar cross section, radio frequency wave pattern) detected by a spectral signal identifier processor **36**. This fact is the basis for the detection sections **103-105** of the system **100** of the present invention and sections **103-105** is the first function of the system. Using a proven high-end direction finding (DF) high fidelity RF receiver **24** coupled with omnidirectional and directional antennae **12**, **14** and unique created software of the system when the RF signature of the sUAS flying within the system's detection boundaries is detected, for example within maximum lateral distance of about 2 kilometers (6560 feet) and within the aerial boundaries up to a maximum altitude of about 1.5 kilometers (4920 feet) above ground level (AGL). This element of the system may be augmented and is shown with additional signature detection elements consisting of acoustic and/or radar sensors **43** and electro optical sensors **16**. These elements operate with unique software translating discernable signatures into coherent data aiding in the detection and location process. All signature data is then processed to generate a reference azimuth and elevation **26**, **46** from the sensor to the subject sUAS **44**. The information generated by the systems detection section is then passed electronically to the direction and range estimation processor **32** to yield a target's location. The system **100** of the present invention uses the hardware and software of the Radio Frequency (RF) detection section **103** to identify the type of sUAS and the associated known and observed radio frequencies signatures required for the sUAS communications and video data exchange.

A second function of the system is providing countermeasures against sUAS that is determined to be a threat in or approaching the vicinity of a property, place, event or VIP. Azimuthal data for a sUAS is determined by the detection section **103-105** of the system. The system's control software/hardware provides this information to the integrated

Electro-Optical (EO) and Infrared (IR) sensor **16** which autonomously centers the field of regard of the EO/IR sensor to the known location of the subject sUAS **44**. When the visual identification is confirmed to be a sUAS; by either video analytics or human verification, the system of invention's software/hardware will then determine the precise x, y, z coordinates (x=longitude, y=latitude, z=altitude) of the sUAS. This precise location and range information is provided to the countermeasure and deterrent section **102** of the system **100**. Using this data the countermeasure and deterrent section **102** computes the RF spectral characteristics that will nullify signals that the sUAS expects to receive. A signal generator **34** produces a tailored signal and a variable strength amplifier **28** generates the output power required; causing the desired effect at the desired range to the subject sUAS **44**. The countermeasure and deterrent section **102** broadcasts the unique generated RF waveform using highly directional and focused antennae **10**. The system uses Blanking **30** at the time between the last radio transmitting signal and the beginning of the next radio-transmitting signal of the transmitted signal in accordance with the frequency and waveform parameters **40** to avoid negative internal effects to system **103**. The system then disables the sUAS sensors, or causes the sUAS navigation system to malfunction due to communication interference causing most sUAS to enter a "Fail Safe Mode" (either land immediately or return to the launch point). This action is sUAS specific and is based on the manufacturer design and sUAS operational capabilities.

The interdict element of a system of the present invention interdicts the operation of an sUAS initially in a non-destructive manner, increasing to a destructive manner based on the response of the target sUAS. A system of the present invention may interdict the operation of a sUAS in a non-destructive manner by transmitting a concentrated Radio Frequency (RF) emission tuned to the specific sUAS characteristics identified by the spectral analysis during the detection process. These RF waveforms are then used to disrupt the expected inputs to the onboard controller of the identified sUAS. The video downlink signal is the initial target of the interdiction process. If this interruption is not sufficient to deter the sUAS, the RF transmitter will be tuned to the appropriate control frequency to disrupt the sUAS on-board electronics. These actions will cause most sUAS to enter the Fail Safe Mode (either land immediately or return to the launch point). The present invention considers the differences based on the manufacturer design and operational capabilities of the sUAS on a case-by-case basis and tailors the inventions countermeasure/deterrent response accordingly.

The countermeasure and deterrent section **102** of the system **100** interdicts the operation of an sUAS in a non-destructive manner by using the non-destructive technology described to generate a interdict transmission signal that is significantly stronger than control signals from an operator of the sUAS. This interdict transmission will have significantly higher gain (Stronger Signal) and target both the sensor and the control electronics of the sUAS. The interdiction process may be augmented with electro-magnetic pulse technology, pulsed laser and is specifically designed to accept other current or future counter-measures used to defeat the sUAS' electronics, motors and or navigation systems. The effects of the higher gain radio transmission will cause amongst other effects, servo-chatter, resulting in the loss of control of the sUAS and disruption of most on-board electronic processes increasing the probability of a forced landing. In addition, a counter sUAS can be dispatched with autonomous navigation data being supplied by the system of present invention to locate and intentionally disable the opposing sUAS by flying into it, dropping a net on the threat, covering it with spray foam or liquid or capturing the opposing sUAS.

The system of the present invention will use direction finding (DF) equipment **12**, **16** to search for the radio communications link of an airborne sUAS **44**, commonly referred to as a drone. Integrating multiple Direction Finding (DF) equipment **26**, **46** to the system of the present invention will increase the precision in obtaining the azimuth that the sUAS is flying. Integrating radar equipment **43** provided with a radar clutter and target filter processor **45**, with the direction finding (DF) equipment will provide the present invention the ability to determine with greater accuracy the altitude and azimuth of the sUAS **44** at the time of discovery and during the time it remains within the systems detection boundaries.

When the DF equipment **26**, **46** has detected a communication link of a sUAS within the system boundaries, the receive host workstation **24** will analyze the radio frequency wave signature and confirm that the RF detected is from a sUAS. This process also applies when a radar unit **43** is integrated with the DF equipment.

The information obtained from DF **26**, **46** and or radar unit **43** is then sent to the direction detect and range estimation unit **32** where algorithms will be used to send sUAS location coordinates to the Automatic Antenna Alignment Assembly (A**4**) **22**, **18**. Put another way, using Slew To Cue, the autonomous actions of electronic, radio or optical sensors to rotate using an automatic antenna alignment assembly **18**, **22** to move and point cameras **16** and countermeasures in the direction of a suspect target **44** based on input from data processed by the azimuth and elevation unit **26 46**, thus, keeping the "cued" targets in view at all times with or without human intervention. This information will then direct the Automatic Antenna Alignment Assembly (A**4**) **22** to point the Electro-Optical and Laser Range Finding unit **16** at the sUAS to allow for visual confirmation, distance and elevation of the sUAS to be known.

The information obtained by the Laser Range Finding equipment will be sent to the Azimuth and Elevation Vector Coordinate Data unit **26** which will send exact azimuth and elevation information to the A**4** system **18** controlling the Matrix Directional Transmit Antenna Array **10** via the Direction Detect and Range Estimation unit **32**.

When the communications link between the subject sUAS and its' operator is detected by the Radio Frequency (RF) detection section **103** of the system the information is passed through the Multiband LNA Assembly **20** and through the Uplink Receive Host Workstation **24**. The information is then sent to the Spectral Signal Detect and Type Identification unit **36** where the type of sUAS is determined based on a known database containing Spectral Signal Wave information **36**. When the Spectral Signal Wave information is known the information is sent to the Frequency and Wave Form Parameters unit **40** where the analyzed RF data is sent to the Modulation Look Up Table **42**. When the Modulation information is known the information is then sent to the ECM Modulation Type Select unit **38**.

The selected modulation waveform is then sent to the Uplink Video Transmitter Assembly **28** that unit works in conjunction with the Receive Blanking unit **30**. When the Uplink Video Transmitter **28** is transmitting a radio signal the Receive Blanking unit **30** will force the DF antennae **12**, **14** to stop receiving the radio frequency being transmitted by the Matrix Directional Transmit Antenna Array **10**. The radio frequency selected to disrupt the communication link of the sUAS with its' operator is then transmitted by the Transmitter Assembly **28** using the Matrix Directional Transmit Antenna Array **10** aimed at the sUAS **44** via the Automatic Antenna Alignment Assembly **18**.

While the invention has been described with reference to certain exemplary embodiments, obvious modifications and alterations are possible by those skilled in the related art. Therefore, it is intended that the invention include all such modifications and alterations to the full extent that they come within the scope of the following claims or the equivalents thereof.

What is claimed is:

1. A target detection system for detecting small unmanned systems such as drones, the target detection system comprising:

a first data connection that receives (a) radar-detected azimuth and elevation data of a target and (b) target range information;

a second data connection that receives radio frequency spectral analysis data of target radio frequency signals that identifies or classifies the target; and

at least one processor operatively coupled to the first and second data connections, the at least one processor including a direction and range estimation processor configured to develop, from the received azimuth and elevation data and the target range information, data indicating target location in a three-dimensional coordinate system where three coordinates specify the position of the target in three-dimensional space.

2. The system of claim **1** wherein the direction and range estimation processor is configured to develop data indicating said target location for unmanned systems including unmanned aerial systems weighing less than 55 pounds.

3. The system of claim **1** wherein the radar-detected azimuth and elevation data comprise data detected by a low power x-band radar.

4. The system of claim **1** further including a further data connection that receives azimuth and elevation data of the target an optical sensor detects independently of the radar, wherein the direction and range estimation processor uses both the azimuth and elevation data detected by the optical sensor and the azimuth and elevation data detected by the radar.

5. The system of claim **1** wherein the at least one processor produces sensor movement control signals to control tracking movement of at least one sensor, and the at least one processor produces tracking data values to slew the tracking movement of the at least one sensor thereby tracking the target.

6. The system of claim **5** wherein the at least one sensor comprises a directional radio frequency receiving antenna connected to RF spectrum analysis hardware and software that produces the radio frequency spectral analysis data.

7. The system of claim **1** further comprising a further data connection that provides radio frequency receiver data corresponding to signals received by an omnidirectional radio frequency receiving antenna and a directional radio frequency receiving antenna.

8. The system of claim **1** wherein the at least one processor is configured to produce classification data that classifies objects of interest as targets and identifies unmanned vehicles utilizing multiple databases or libraries created and categorized with spectral signatures for unmanned vehicles.

9. The system of claim **8** wherein the spectral signatures include sound, heat, radar data, and/or radio frequency wave pattern.

10. The system of claim **1** further including a direction finding receiver configured to produce search data for the target.

11. The system of claim **1** wherein the at least one processor is configured to produce data that controls the direction of an automatic antenna alignment device to thereby track the target.

12. A target detection system for detecting small unmanned systems including drones, the target detection system comprising:

at least one radar configured to detect first azimuth and elevation data of a target;

at least one optical sensor configured to detect second azimuth and elevation data of the target;

at least one of the radar and the optical sensor producing target range information;

at least one radio frequency receiver configured to identify the target using radio frequency spectral analysis of radio frequency signals received from the target; and

at least one processor operatively coupled to the at least one radar, the at least one optical sensor and the at least one radio frequency receiver, the at least one processor including a direction and range estimation processor configured to use the first and second detected azimuth and elevation data and the range information to determine target location in a three-dimensional coordinate system where the target location comprises three coordinates that together specify the position of the target in three-dimensional space.

13. The system of claim **12** wherein the system is configured to detect unmanned aerial targets that weigh less than 55 pounds.

14. The system of claim **12** wherein the radar comprises a low power xband radar.

15. The system of claim **12** wherein the optical sensor detects azimuth and elevation data of the target independently of the radar.

16. The system of claim **12** wherein the at least one processor produces sensor movement signals, and implements slew to cue to track the target.

17. The system of claim **16** wherein the at least one sensor comprises a directional radio frequency receiving antenna that tracks the target using the slew to cue.

18. The system of claim **12** further comprising an omnidirectional radio frequency receiving antenna and a directional radio frequency receiving antenna configured to receive radio signals emitted by the target.

19. The system of claim **12** wherein the at least one processor detects and identifies unmanned vehicles utilizing a database library comprising spectral signatures.

20. The system of claim **19** wherein the spectral signatures include sound, heat, radar cross-section, and/or radio frequency wave pattern.

21. The system of claim **12** further including a direction finder to search for the target.

22. The system of claim **12** wherein the at least one processor controls the direction of an automatic antenna alignment target tracker.

23. The system of claim **12** wherein the at least one processor performs image recognition algorithms.

* * * * *