



(51) International Patent Classification:

<i>B64C 39/02</i> (2006.01)	<i>G05D 1/10</i> (2006.01)
<i>G01C 21/00</i> (2006.01)	<i>G08G 5/00</i> (2006.01)
<i>G01C 21/20</i> (2006.01)	<i>G08G 5/04</i> (2006.01)
<i>G05D 1/00</i> (2006.01)	

(21) International Application Number:

PCT/US2017/014215

(22) International Filing Date:

20 January 2017 (20.01.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/286,286 22 January 2016 (22.01.2016) US

(72) Inventor; and

(71) **Applicant : RUSSELL, David Wayne** [US/US]; 107 Desiree Aurora St., Winter Garden, FL 34787 (US).

(81) Designated States (*unless otherwise indicated, for every*

kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN,
 KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA,
 MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
 NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
 RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY,
 TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN,
 ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every*

kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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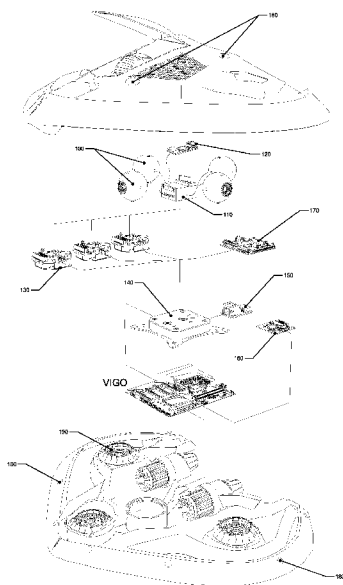
— *of inventorship (Rule 4.17(iv))*

Published:

— with international search report (Art. 21(3))

(54) Title: SYSTEM AND METHOD FOR SAFE POSITIVE CONTROL ELECTRONIC PROCESSING FOR AUTONOMOUS VEHICLES

FIG. 1



(57) Abstract: In order for Unmanned Autonomous Vehicles (UAVs) to gain acceptance for operating in close proximity to human beings they must be first and foremost designed for safety. This invention discloses a safe positive control electronic processing system for autonomous vehicles comprised of some combination of independent simultaneously operating sub-systems in hardware and/or software such as but not limited to a navigation system which follows a predefined space and time trajectory data structure, 3D or 4D inverse-geofence or Free Flight Corridor definition, and/or a Situational Awareness functionality which can select alternative navigation paths, functions, behaviors, or system parameters based on the application programming of the vehicle.

SPECIFICATION

TITLE OF INVENTION

System and Method for Safe Positive Control Electronic Processing for Autonomous Vehicles

INVENTORS

David Wayne Russell, (USA) Winter Garden, Florida USA

CROSS-REFERENCE TO RELATED APPLICATIONS

US 62/286,286 1/22/2016

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR
DEVELOPMENT

Not Applicable

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM
LISTING COMPACT DISK APPENDIX

Not Applicable

FIELD

[0001] This invention relates generally to the field of automatic or autonomous vehicles and more specifically to a safe positive control processing system for autonomous vehicles.

BACKGROUND

[0001] In designing a Vehicle Control System (VCS) for autonomous vehicles, many designers are simply focused on getting the vehicle to work, sometimes with less concern given with regard to the safety of human beings that may exist within the Area of Operation (AO).

[0002] This invention is primarily concerned with providing a system and methodology for the creation of a VCS that is designed from first principles with the safety of humans in mind. To accomplish this we must first have a working definition of what safety means in the autonomous vehicle environment. Secondly, an architecture and methodology must be devised which meets both the required definition of safety and the functional needs of an autonomous vehicle.

[0003] For the purposes of autonomous vehicles, one definition of safety would encompass three major traits: First, the safety of the general populace in the Area of Operation must be paramount, and may be designed to functional safety specifications such as IEC61805. Second, high accuracy in following detailed precomputed navigation is required combined with a methodology of confirming the platform is operating within a known safe corridor. Finally, safety mechanisms to mitigate terminal velocity and/or mitigate impact force of the platform should be included in the worst case scenario.

[0004] In most attempts at designing an autonomous vehicle, the approach is to design in software an analog of the processing performed in a human brain in performing the same actions, under the premise that if humans do it well the machine should work in the same way. Human brains, however, and electronic processing systems have fundamental differences which makes this premise difficult to realize at best. It is possible but it is also either very difficult or very expensive or both.

[0005] The software version of the control system becomes significantly more complex when it tries to solve all of the problems associated with vehicle autonomy at once. In addition, general purpose computers are essentially designed to do everything poorly. They are capable of doing anything, but inherent in that flexibility is a tradeoff of processing speed.

[0006] Hardware accelerators have long been shown to be successful in implementing specific problem solutions at very high speeds. In this invention, the functionality of the Safe Vehicle Control System (SVCS) is broken into a hierarchical or tiered series of functions which are well-suited for implementation by electronic processing systems and with this architecture each step is significantly simpler and faster than an algorithmic aggregation.

[0007] Waypoints are often used to create multifaceted trajectories for an unmanned vehicle. These waypoints may be tens, hundreds, or thousands of meters apart, leaving the platform to negotiate the intermediate space on its own, and creating a very large area of unknowns as to where the vehicle is at any point in time. This leads to inaccuracies in vehicle tracking and problematic air traffic control when choke points or busy corridors arise from the inevitable increase in traffic.

[0008] Legal standards for drone platforms, Safe Autonomous Light Aircraft (SALA), Air Traffic Control (ATC) and even privacy issues are evolving rapidly. A system and methodology is desired which will meet the high standards of safety, accuracy, and flexibility that will be demanded of autonomous vehicles in close proximity to human beings.

BRIEF SUMMARY OF THE INVENTION

[0009] The first level of the implementation is the trajectory management system which will hereafter be referred to as the trackpath. This is a human-created or automatically generated four-dimensional path through space and time. The overall path is mathematically described such as but not limited to a spline, which enables the platform to interpret the spline to any level of mathematical accuracy that is permissible and/or appropriate.

[0010] Creation of this trajectory is the most computationally intensive task of the automation process, potentially requiring a 4-Dimensional Autorouter, and while it can be performed within the vehicle control system it may be easier and more efficient to implement as part of a vehicle Traffic Control System (TCS) similar in concept to the existing Air Traffic Control (ATC) system for aircraft. It must be noted, however, that the trackpath is not limited to air vehicles and is equally applicable to road, surface, and subsurface trajectories.

[0011] The trackpath also defines a Free Flight Corridor (FFC) structure, which is a 4D virtual construct that separates the allowable area for vehicle operation from other vehicles or those areas where humans may be present and require protection. The vehicle is designed to stay within this corridor, in contrast a Geo-Fence or similar construct is used to keep the platform out of a defined area and is usually more limited in dimensionality.

[0012] In practical use, utilization of a GeoFence construct allows the vehicle to go anywhere not expressly prohibited, and it is much more difficult to maintain within the platform all of the potential “no fly” areas in real time. The 4Dimensional trackpath system is precomputed at a time when all available domain knowledge, 3D models of the AO, and all other vehicle information is available, such that the platform must stay within its FFC. This is the only safe operational configuration.

[0013] In one embodiment the VCS is designed to prevent the vehicle or any portion or debris thereof from crossing the FFC. The Free Flight Corridor is also mathematically defined which

makes it much more accurate than a GPS position or corridor. The trackpath is also a programming language which enables the platform to select from a pre-stored set of multiple contingency trackpath structures including base plus offset navigation constructs, and select a new trackpath or even modify an existing one based on conditions detected by or transmitted to the platform.

[0014] The second tier of the control system is the VCS trajectory management (navigation system) within the vehicle itself, such as but not limited to a Safe Temporal Vector Integration Engine (STeVIE). This system is the navigator, and is primarily responsible for determining a single temporal vector that defines the movement of the platform from the current point in space to the next point in space and time as defined by the trackpath. STeVIE is simplified by modeling the vehicle as single point in space, and utilizing one coordinate system for all operations. STeVIE operates at very high speeds providing for example without limitation 1,000,000 vectors per second, equivalent to 0.001 inches of platform travel at 60MPH. One practiced in the art would recognize that other implementations of hardware and software could be applied to implement similar strategies without compromising the unique aspects of this invention.

[0015] These calculations are only as accurate as the position fix the platform is able to achieve. To this end a system which can anticipate and interpolate platform sensor variables may be implemented to provide high speed and accuracy modeling of the flight variables.

[0016] In order to prevent hardware failures within the vector integration engine, multiple navigation units are instantiated in the design, potentially with different combinations of the overall input data sensor sets. The multiple temporal vectors produced are weighed within a final comparator, resulting in for example but not limited to a vote-driven collaboration of two vectors, an average of three, or a fault determination triggering terminal guidance.

[0017] The final layer of the implementation is the physical layer such as but not limited to a Vector-In Guidance-Out (VIGO) processor. VIGO is simplified because it needs to know little about the complexities of the navigation, trackpath, and associated information. It simply takes the temporal vector provided by navigation and modifies the control surfaces and control electronics of the physical vehicle platform to implement that vector in real time. While each layer of this control system is greatly simplified, the overall functions performed are

operationally equivalent to much more complex software implementations of autonomous vehicles at much greater speed.

[0018] Processing speed of the VCS is of utmost importance because speed greatly impacts the numerical and physical range of the control inputs to the system and the related physical path the vehicle takes. A standard “drone” platform or UAV, for example, at 60MPH might update its GPS flight variables about every 9 feet. Control variable changes invariably cause perturbations, often non-linear in nature, in the control system in general resulting in undershoot, overshoot, and oscillation. When these oscillations are on the order of feet, this is a significant problem for a vehicle and the safety of all nearby. At 60MPH and 1,000,000 vectors per second the navigation system is updating its flight control vector approximately every 0.001 inches, and at these scales the control system perturbations become virtually nonexistent and may be tuned to keep some non-linear control variables within a linear domain envelope for further simplification.

BRIEF DESCRIPTION OF DRAWINGS

[0019] The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical components or features.

[0020] The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives, and features thereof will best be understood by reference to the following detailed description of illustrative embodiments of the present disclosure when read in conjunction with the accompanying drawings, wherein:

[0021] FIG. 1 shows an overall diagram of the subsystems which comprise a positive control electronic processing system.

DETAILED DESCRIPTION OF INVENTION

[0022] The following detailed description illustrates embodiments of the invention by way of example and not by way of limitation. The description clearly enables one skilled in the art to

make and use the disclosure, describes several embodiments, adaptations, variations, alternatives, and use of the disclosure, including what is currently believed to be the best mode of carrying out the disclosure. The disclosure is described as applied to an exemplary embodiment namely, systems and methods for the creation of a safe vehicle control system. However, it is contemplated that this disclosure has general application to vehicle management systems in industrial, commercial, military, and residential applications.

[0023] As used herein, an element or step recited in the singular and preceded with the word "a" or "an" should be understood as not excluding plural elements or steps, unless such exclusion is explicitly recited. Furthermore, references to "one embodiment" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0024] Referring now to the invention in more detail, in Fig. 1 there is shown an overall diagram of a flight plan generation system. The different illustrative embodiments recognize and take into account a number of different considerations. "A number", as used herein with reference to items, means one or more items. For example, "a number of different considerations" means one or more different considerations. "Some number", as used herein with reference to items, may mean zero or more items.

[0025] In FIG. 1 the diagram depicts the components of one possible embodiment of a vehicle control system. The primary differences in many of these systems are the combinations of sensors which are available to the VCS. In this embodiment the sensor suite contains one or more 3D camera imaging systems 100 which may be attached to a pan/tilt/zoom configurable platform or in other embodiments multiple imaging systems of differing type, capability and mix of fixed or moveable mounts may be deployed simultaneously to provide better situational awareness. These imagers may rely for example on different techniques such as but not limited to IR, visible light, or RF or IR beacons, audio location systems, 3D model landmarks, cellular tower or known aircraft navigation bearings.

[0026] The most ubiquitous location sensing system is the Global Position System (GPS) 110 or its equivalent in this other countries. In some areas Enhanced GPS (E-GPS) may be available to provide additional accuracy to the fix, or in some military applications the full accuracy of the GPS system may be available. In fixed locations, such as autonomous vehicles performing in an

arena or theme park environment or underwater autonomous vehicles, audio-based location systems 120 are also possible to implement.

[0027] With situational awareness and location provided by these systems, in one embodiment three navigation processors 130 simultaneously compute the difference vector between the trackpath data structure they are attempting to follow and their current location. These three resultant vectors are input to the overall Navigation System Processor (NSP) 140 which also may also connect to the Identify Friend or Foe (IFF) transponder 150 which communicates with and may receive instructions from an overall Air Traffic Control (ATC) for UAVs and other autonomous craft.

[0028] The resultant temporal vector is either passed to the Vector-In Guidance-Out (VIGO) processor for implementation on the platform, or if there is an error condition in the navigation processors then vectors from the Terminal Guidance System 160 are passed in instead.

[0029] Decisions regarding platform variables such as but not limited to the trackpath being followed are handled by the Scene Analysis System (SAS) 170. The SAS may be implemented once for the entire platform or once for each navigation processor or some combination thereof. The SAS may also provide obstacle avoidance situational awareness for the platform or work in conjunction with a separate obstacle avoidance subsystem. The resources of the SAS and obstacle avoidance systems may also be made available to or shared with the Terminal Guidance Controller.

[0030] If conditions programmed for detection by the trackpath data structure occur, the NSP switches the active trackpath to the navigation plan specified by the logic system. It may do this on the fly or it may first go to a hover mode, switch paths, and then begin executing. In some ATC environments the platform may be pre-cleared for the eventuality of this maneuver or the NSP may have to receive confirmation from the ATC before it continues. The combination of the SAS and the NSP provide for a real-time tracking mode where rough parameters of the trackpath are merged with tracking bearings from the SAS in the navigation processors. In another embodiment the Terminal Guidance System could also be utilized for tracking mode. This may require specific permission and/or a priority clearance from the ATC.

[0031] VIGO receives possibly interpolated sensor data from physical altitude and attitude sensors 180, controls and defined motor, control surface, and ducted fan gimbal settings 190. In other embodiments VIGO could control land-based, surface or subsurface vehicles with different motor types and control surfaces.

[0032] In use, a user or automated launch control system requests a trackpath from the vehicle control authority. In one implementation this might be an individual requesting block permission via mobile device to fly a UAV within a park or within the coordinate space of a house being photographed.

[0033] In another embodiment an automated package delivery system might require a trackpath from a given launch point at the fulfillment facility to a particular drop-off point some distance away. In either case the Vehicle Traffic Control system calculates the trackpath trajectory, timing, and FFC specifications and transmits this data to the platform. At the time or time window prescribed by the trackpath, the vehicle executes the trajectory plan.

[0034] To execute the plan the Flight Control System such as but not limited to a VIGO processor, begins motor and attitude control initialization and startup. Simultaneously the SAS and object avoidance systems initialize and form an initial situation awareness sweep of the environs. The Navigation Control System such as but not limited to a STeVIE processor selects the initial trackpath, prepares the initial vector, synchronizes its timing with the overall control system and awaits the designated start time.

[0035] Once in flight, the navigation system, scene analysis system, obstacle avoidance system, flight control system, and safety systems all operate simultaneously and independently, which is not possible in real time in a software system combining these functions. The predominant operation of the platform is for the navigation control system to follow the trackpath trajectory information in space and time, while avoiding obstacles through information provided by the SAS and object avoidance systems.

[0036] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiment, method, and examples herein. The invention should therefore not be

limited by the above described embodiment, method, and examples, but by all embodiments and methods within the scope and spirit of the invention. Further, different illustrative embodiments may provide different benefits as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

[0037] The flowcharts and block diagrams described herein illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various illustrative embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function or functions. It should also be noted that, in some alternative implementations, the functions noted in a block may occur out of the order noted in the figures. For example, the functions of two blocks shown in succession may be executed substantially concurrently, or the functions of the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.

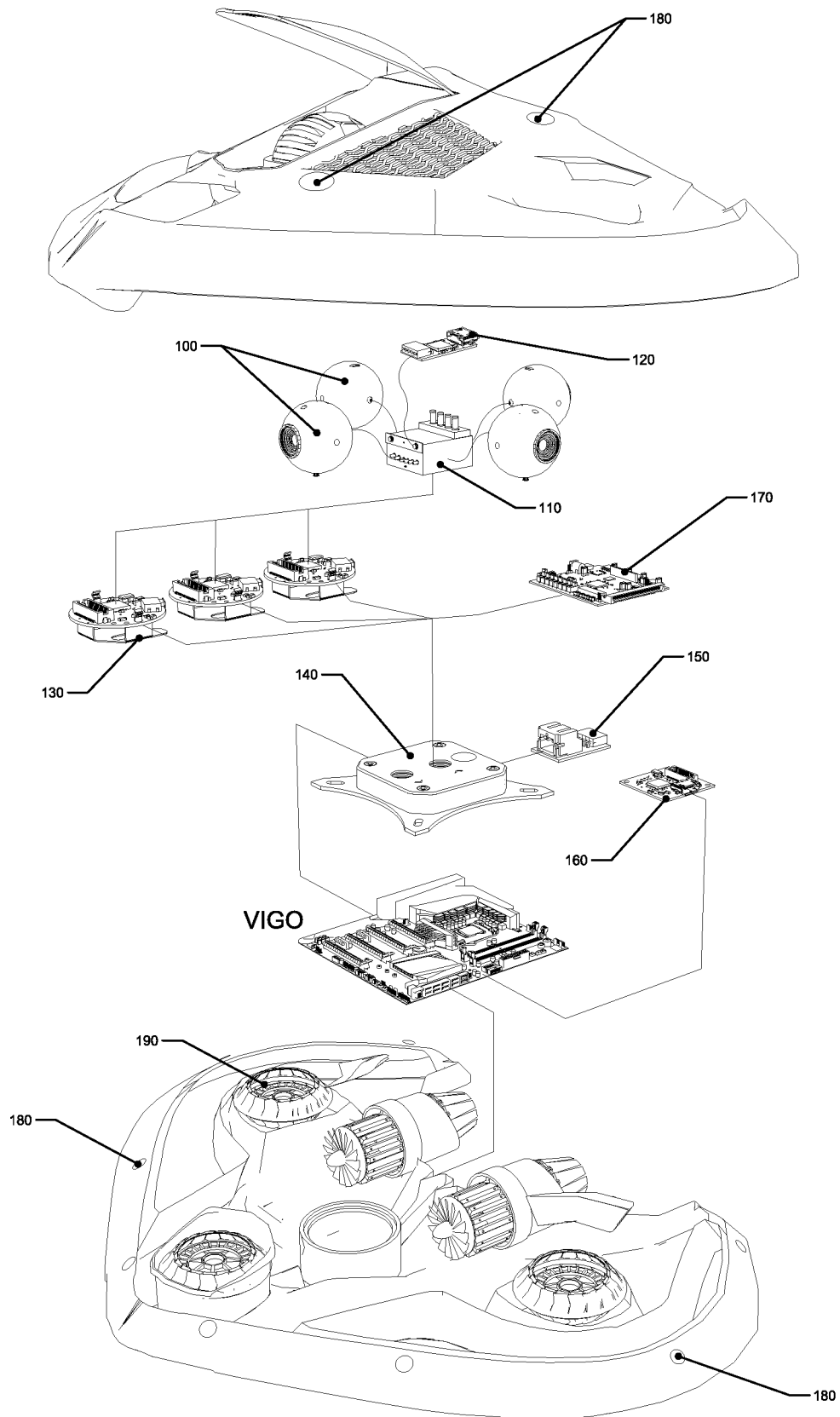
CLAIMS

The invention claimed is:

- 1) An autonomous vehicle control system comprised of some combination of independent simultaneously operating subsystems in hardware and/or software such as but not limited to a navigation system which follows a predefined space and time trajectory data structure, 3D or 4D inverse-geofence or Free Flight Corridor definition, and/or a Situational Awareness functionality which can select alternative navigation paths, functions, behaviors, or system parameters based on the application programming of the vehicle.
- 2) The system of 1 which utilizes predictive interpolation of sensor signals to increase accuracy and sample speed to other vehicle subsystems including those described in (1).
- 3) The system of 1 which utilizes some number of imaging systems within the situational awareness and/or obstacle avoidance functions.
- 4) The system of 1 where the safety boundary and navigation trajectories are created by utilization of a 3D or 4D autorouter.
- 5) The system of 1 where the safety boundary and navigation trajectories are created by a graphical user interface and computing system such as but not limited to a 3D or 4D graphical editing system.
- 6) The system of 1 where the safety boundary and navigation trajectories take other vehicles and/or moving objects into account at creation.
- 7) The system of 1 where the continuous description navigation path is a series of splines.
- 8) The system of 1 where the continuous description navigation path is a series of line segments.
- 9) The system of 1 where multiple independent navigation control systems are used for redundant calculation of the flight navigation information.
- 10) The system of 1 where a Navigation System Processor is utilized to switch between the platform vectors, tracking mode, Terminal Guidance modes, and other implementation modes.

- 11) The system of 1 where one or more scene analysis systems are used to provide logical detection information that is used to switch the platform from one navigation path to another, and/or change system parameters or behavior.
- 12) The system of 1 where one or more Scene Analysis Systems are also used for obstacle avoidance and situational awareness.
- 13) The system of 1 where independent Scene Analysis and obstacle avoidance system both contribute and/or share data to enhance the overall capabilities and situational awareness of the platform.
- 14) The system of 1 where navigation is defined to expressly or implicitly include time as a component of the trajectory.
- 15) The system of 1 which can include application specific programming.
- 16) The system of 1 which includes some form of identification and monitoring system.
- 17) The system of 1 which includes application specific devices and functionality such as but not limited to special effects, lighting, pyrotechnics, aerobatics, smoke, fog, water spray, misters, swarm or formation flight, or confetti.
- 18) The system of 1 which includes independent and/or integrated safety subsystem functions such as but not limited to Terminal Guidance, safety specific landing parameters and control system, parachutes deployed under the direction of the safety system, and/or airbags.
- 19) The system of 1 where the Scene Analysis and/or obstacle avoidance systems may be utilized by the safety Terminal Guidance system during an emergency descent.
- 20) The system of 1 where the Terminal Guidance system may take control of the flight control system and any other system functions (such as but not limited to disengaging a pyrotechnics control system) in the event of an emergency descent or flight operations in an emergency or outside of permitted parameter situation.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/014215

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B64C 39/02; G01C 21/00; G01C 21/20; G05D 1/00; G05D 1/10; G08G 5/00; G08G 5/04 (2017.01)
 CPC - B64C 39/02; B64C 2201/00; B64C 2201/14; G01C 21/00; G01C 21/20; G05D 1/00; G05D 1/10; G08G 5/00; G08G 5/0047; G08G 5/006; G08G 5/04; G08G 5/045 (2017.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 342/63.000; 342/65.000; 342/113.000; 342/118.000; 701/1.000; 701/14.000; 701/24.000; 701/301.000 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2014/0018979 A1 (HONEYWELL INTERNATIONAL INC.) 16 January 2014 (16.01.2014) entire document	1, 3-6, 8, 10-16, 18, 20 --- 2, 7, 9, 17, 19
Y	US 7,386,049 B2 (GARRIDO et al) 10 June 2008 (10.06.2008) entire document	2
Y	US 8,510,029 B2 (CURTIS et al) 13 August 2013 (13.08.2013) entire document	7
Y	US 8,706,394 B2 (TREPAGNIER et al) 22 April 2014 (22.04.2014) entire document	9
Y	US 9,238,177 B2 (SOFMAN et al) 19 January 2016 (19.01.2016) entire document	17
Y	US 2015/0153740 A1 (ELBIT SYSTEMS, LTD) 04 June 2015 (04.06.2015) entire document	19
A	US 6,442,456 B2 (BURNS et al) 27 August 2002 (27.08.2002) entire document	1-20
A	US 8,977,481 B1 (DOWNS) 10 March 2015 (10.03.2015) entire document	1-20
A	US 9,108,729 B2 (DUGGAN et al) 18 August 2015 (18.08.2015) entire document	1-20
A	US 8,543,265 B2 (EKHAGUERE et al) 24 September 2013 (24.09.2013) entire document	1-20
A	US 8,626,361 B2 (GERLOCK) 07 January 2014 (07.01.2014) entire document	1-20
A	US 2015/0094883 A1 (GOOGLE INC.) 02 April 2015 (02.04.2015) entire document	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

07 March 2017

Date of mailing of the international search report

07 APR 2017

Name and mailing address of the ISA/US

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PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/014215

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7,299,130 B2 (MULLIGAN et al) 20 November 2007 (20.11.2007) entire document	1-20
A	US 2010/0001902 A1 (SMITH) 07 January 2010 (07.01.2010) entire document	1-20
A	US 2015/0323930 A1 (UNMANNED INNOVATION, INC.) 12 November 2015 (12.11.2015) entire document	1-20