US 20140231590A1

(19) **United States**

(12) **Patent Application Publication**

Trowbridge et al.

(10) **Pub. No.: US 2014/0231590 A1**

(43) **Pub. Date: Aug. 21, 2014**

(54) **AERIAL DISPLAY SYSTEM WITH MARIONETTES ARTICULATED AND SUPPORTED BY AIRBORNE DEVICES**

(71) Applicant: **DISNEY ENTERPRISES, INC.**, Burbank, CA (US)

(72) Inventors: **Robert Scott Trowbridge**, La Canada, CA (US); **James Alexander Stark**, South Pasadena, CA (US); **Clifford Wong**, Burbank, CA (US)

(73) Assignee: **DISNEY ENTERPRISES, INC.**, Burbank, CA (US)

(21) Appl. No.: **13/768,905**

(22) Filed: **Feb. 15, 2013**

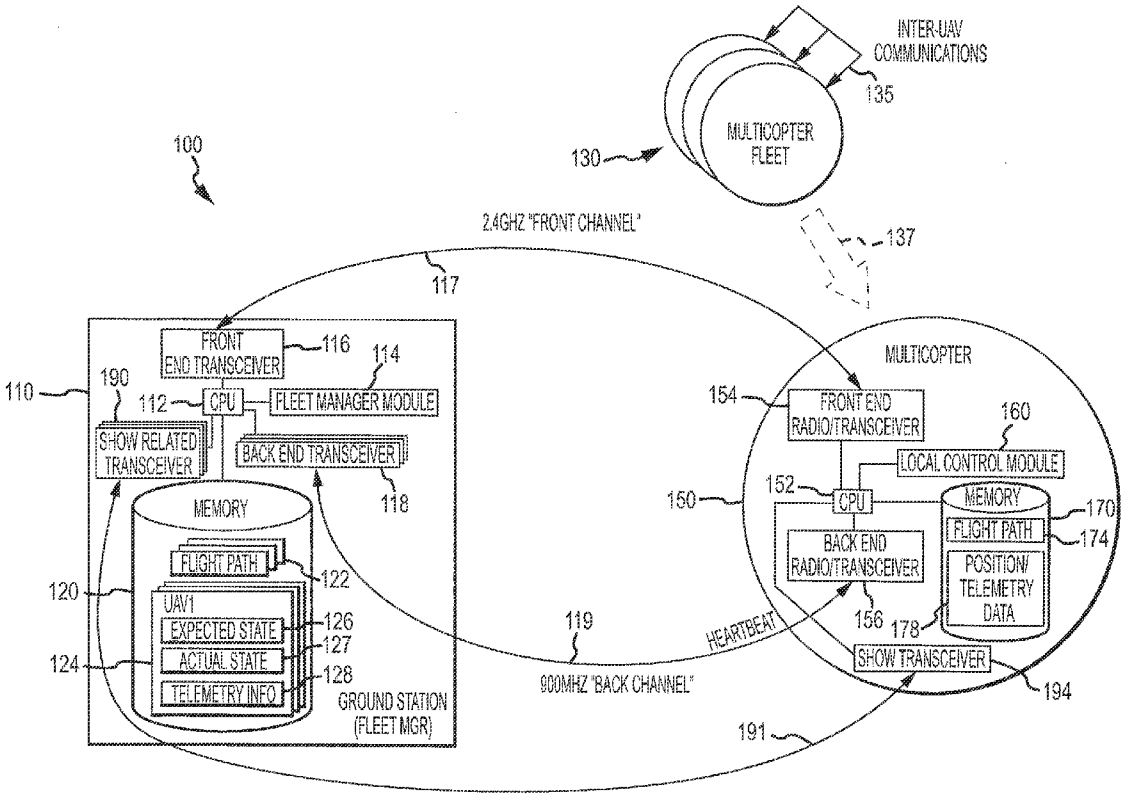
Publication Classification

(51) **Int. Cl.**
B64C 19/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B64C 19/00*** (2013.01)
USPC **244/175**

(57) **ABSTRACT**

A system for performing an aerial display. The system includes a plurality of unmanned aerial vehicles (UAVs) and a ground control system with a processor executing a fleet manager module and with memory storing a different flight plan for each of the UAVs. The system further includes a marionette with a body and articulatable appendages attached to the body. The body and appendages are supported with tether lines extending between the marionette and the UAVs. Then, during a display time period, the UAVs concurrently execute the flight plans to position and articulate the marionette within a display air space. In some embodiments, the UAVs each is a multicopter, and each of the multicopters includes a local controller operating to move the multicopter through a series of way points defined by the flight plan associated with the multicopter.



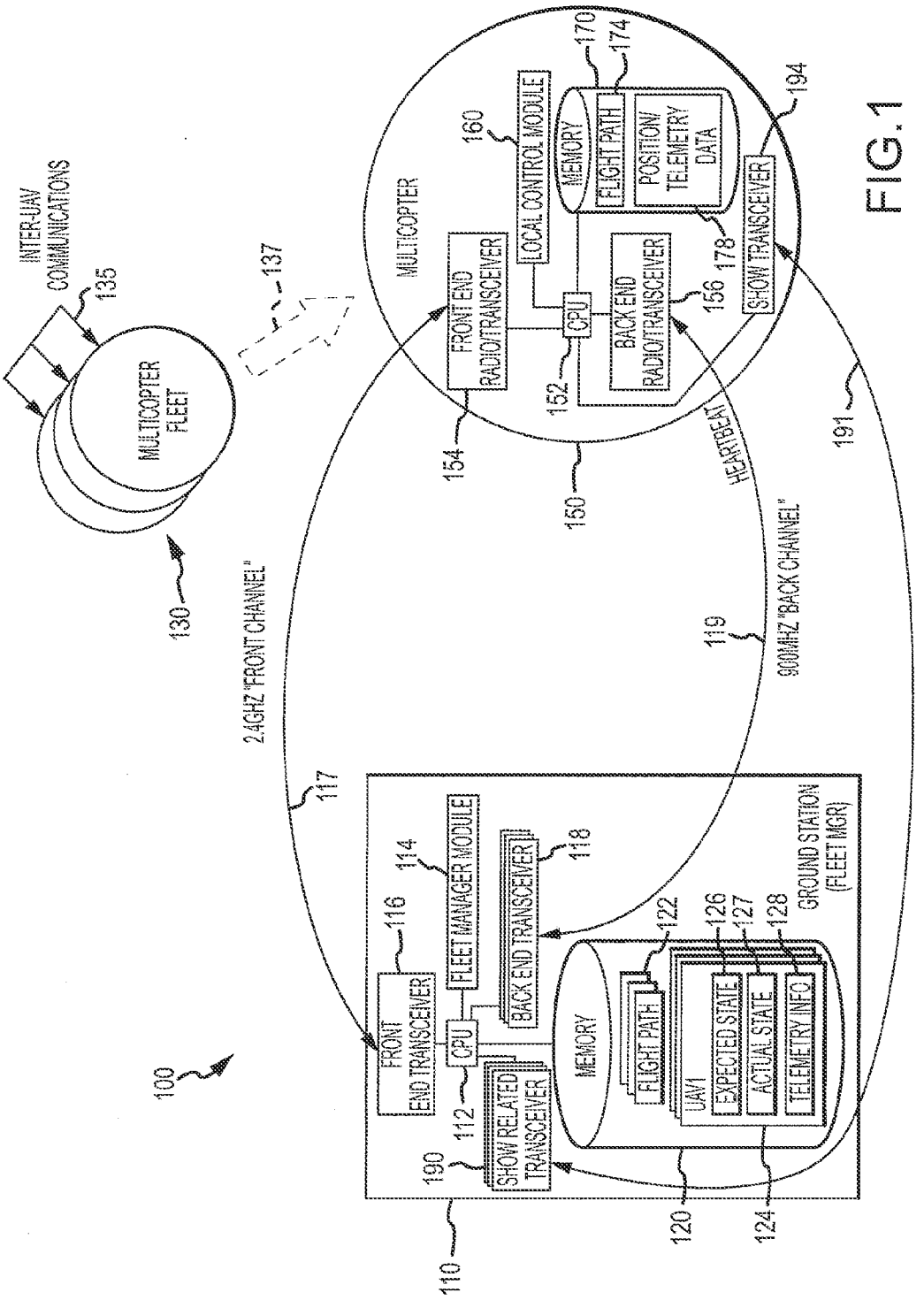

INTER-UAV COMMUNICATIONS
135
MULTICOPTER FLEET
137
130
100
2.4GHZ "FRONT CHANNEL"
MULTICOPTER
160
LOCAL CONTROL MODULE
170
MEMORY
174
FLIGHT PATH
POSITION/ TELEMETRY DATA
194
SHOW TRANSCEIVER
178
FRONT END RADIO/TRANSCEIVER
154
CPU
152
BACK END RADIO/TRANSCEIVER
156
150
HEARTBEAT
191
900MHZ "BACK CHANNEL"
119
117
FRONT END TRANSCEIVER
116
FLEET MANAGER MODULE
114
BACK END TRANSCEIVER
118
CPU
112
SHOW RELATED TRANSCEIVER
190
MEMORY
122
FLIGHT PATH
UAV1
126
EXPECTED STATE
127
ACTUAL STATE
128
TELEMETRY INFO
GROUND STATION (FLEET MGR)
110
120
124

FIG. 1

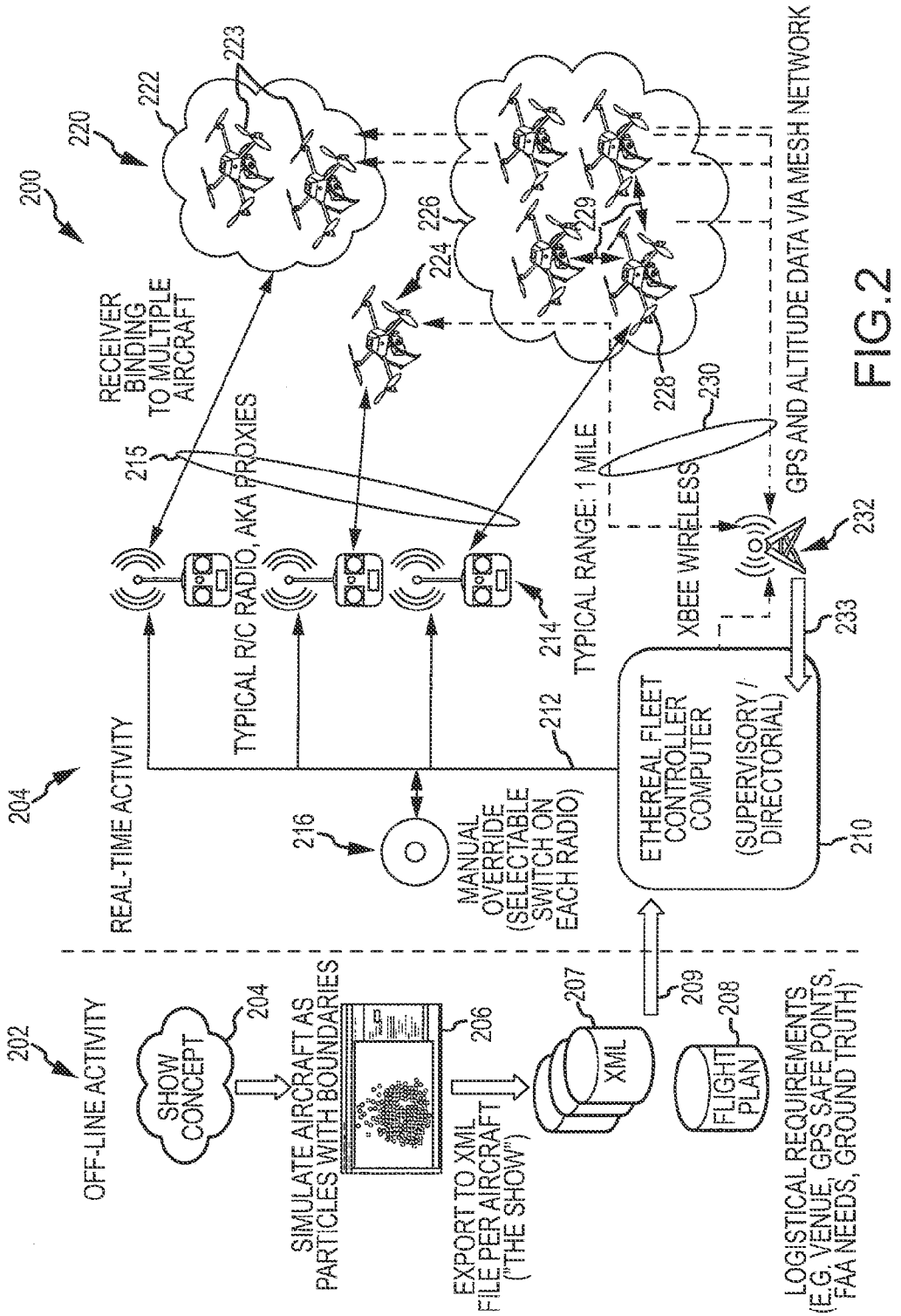

200
220
222
223
224
226
229
228
230
232
233
RECEIVER BINDING TO MULTIPLE AIRCRAFT
215
TYPICAL R/C RADIO, AKA PROXIES
214
TYPICAL RANGE: 1 MILE
XBEE WIRELESS
GPS AND ALTITUDE DATA VIA MESH NETWORK
204
REAL-TIME ACTIVITY
212
216
MANUAL OVERRIDE (SELECTABLE SWITCH ON EACH RADIO)
ETHEREAL FLEET CONTROLLER COMPUTER
(SUPERVISORY / DIRECTORIAL)
210
202
OFF-LINE ACTIVITY
SHOW CONCEPT
204
SIMULATE AIRCRAFT AS PARTICLES WITH BOUNDARIES
206
EXPORT TO XML FILE PER AIRCRAFT ("THE SHOW")
207
XML
209
208
FLIGHT PLAN
LOGISTICAL REQUIREMENTS (E.G. VENUE, GPS SAFE POINTS, FAA NEEDS, GROUND TRUTH)

FIG.2

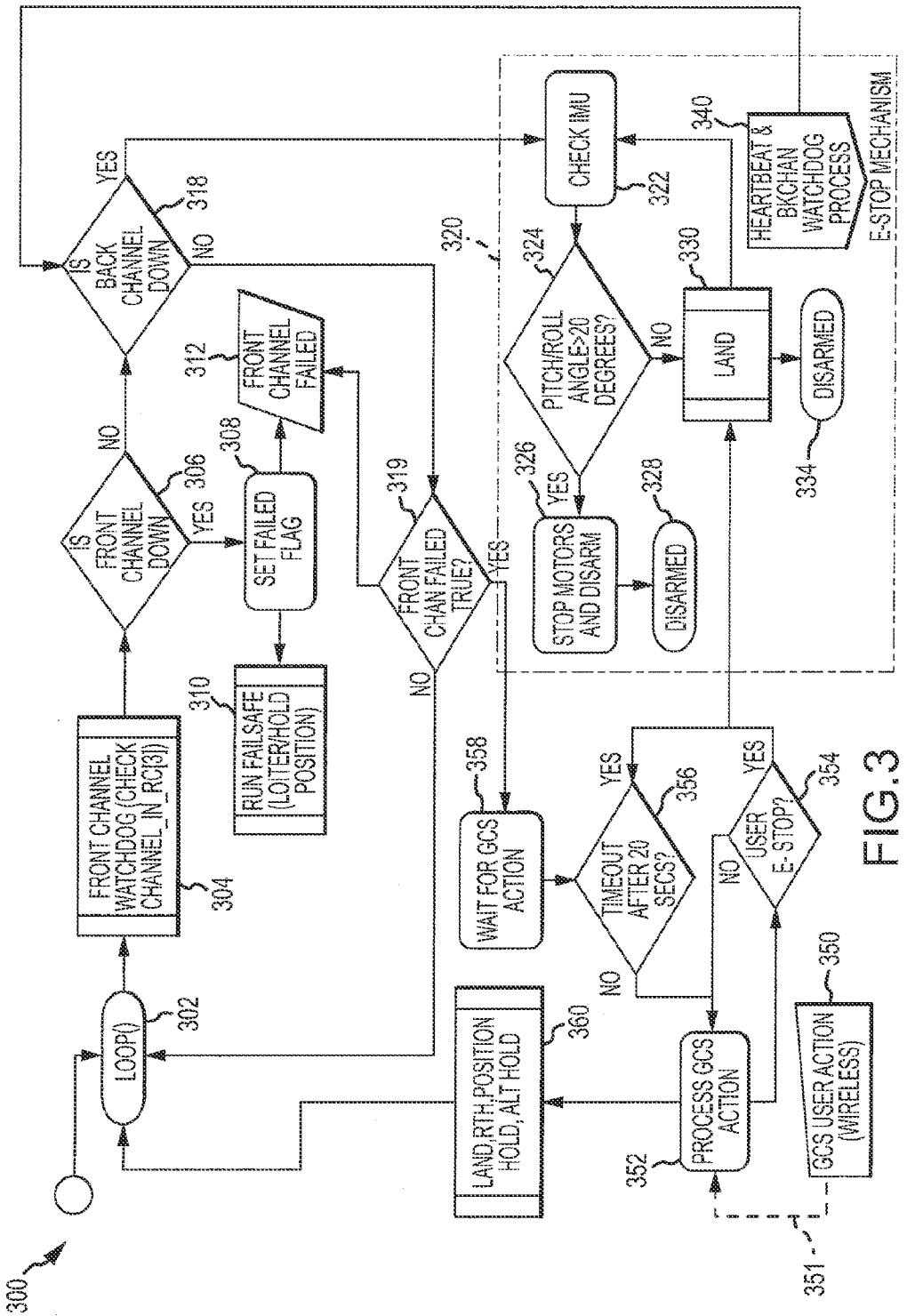

300
LOOP()
302
FRONT CHANNEL WATCHDOG (CHECK CHANNEL_IN_RC(3))
304
IS FRONT CHANNEL DOWN
306
NO
YES
SET FAILED FLAG
308
FRONT CHANNEL FAILED
312
RUN FAILSAFE (LOITER/HOLD POSITION)
310
IS BACK CHANNEL DOWN
318
YES
NO
FRONT CHAN FAILED TRUE?
319
YES
NO
320
CHECK IMU
322
PITCH/ROLL ANGLE>20 DEGREES?
324
NO
YES
LAND
330
DISARMED
334
STOP MOTORS AND DISARM
326
DISARMED
328
HEARTBEAT & BKCHAN WATCHDOG PROCESS
340
E-STOP MECHANISM
WAIT FOR GCS ACTION
358
TIMEOUT AFTER 20 SECS?
356
YES
NO
USER E-STOP?
354
YES
NO
LAND,RTH,POSITION HOLD, ALT HOLD
360
PROCESS GCS ACTION
352
GCS USER ACTION (WIRELESS)
350
351

FIG. 3

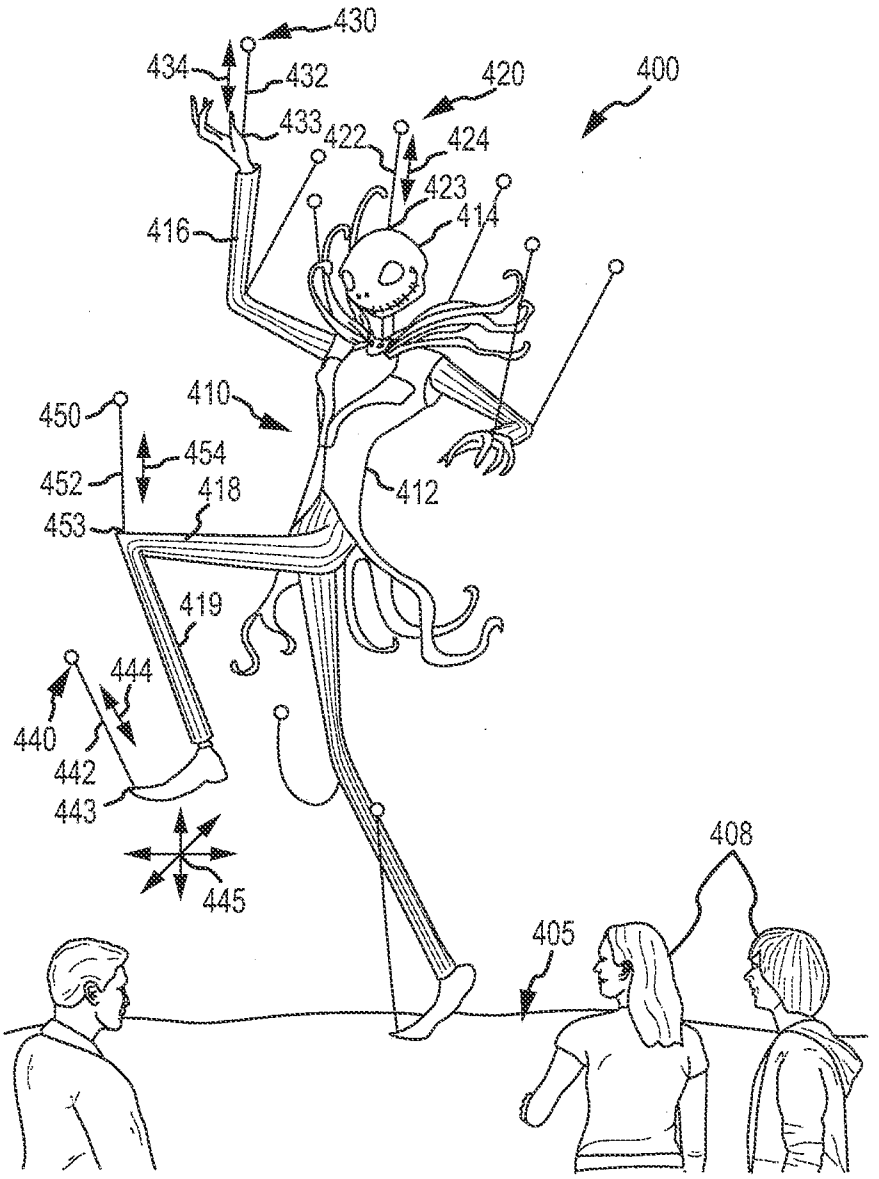

430
434
432
420
400
433
422
424
423
414
416
410
450
454
452
418
412
453
419
444
440
442
443
445
408
405

FIG.4

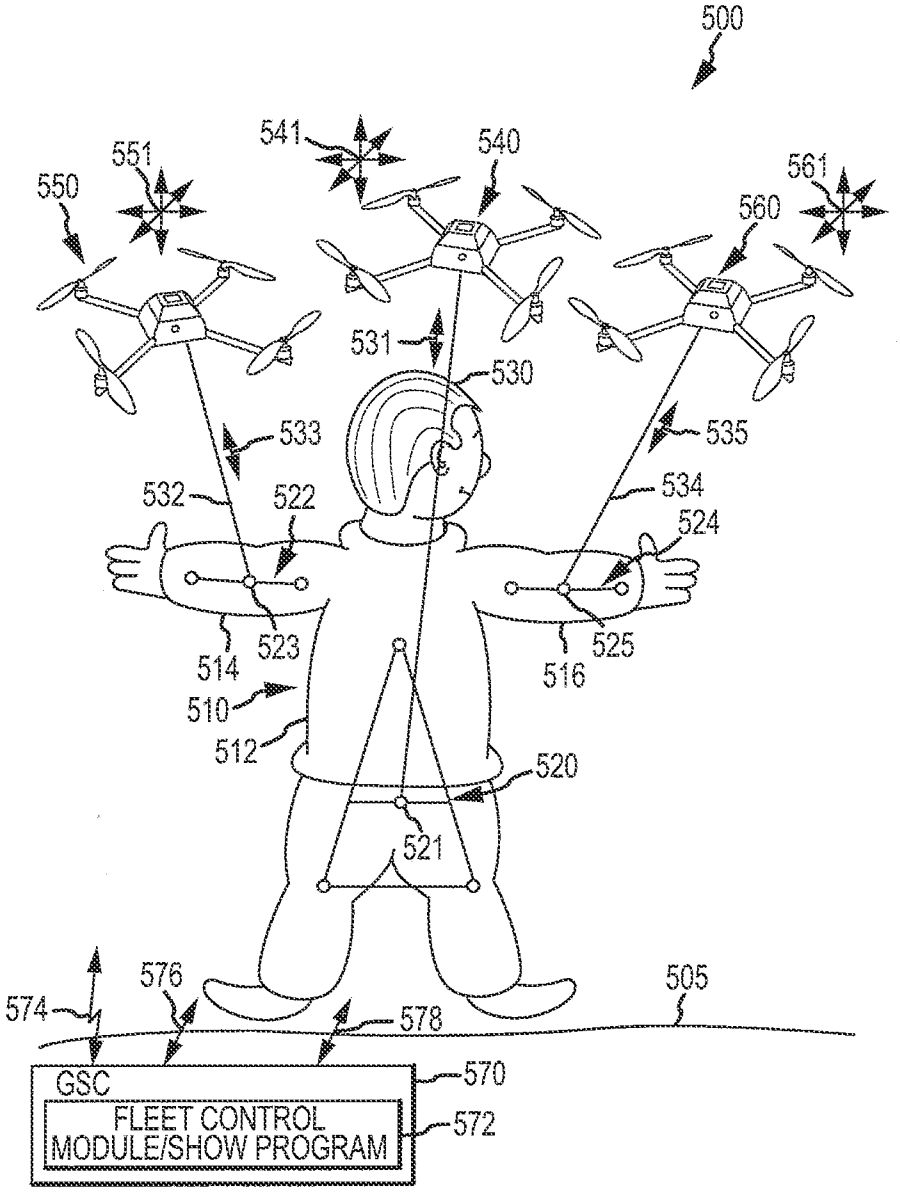

500
541
540
551
550
561
560
531
530
533
535
532
522
534
524
523
525
514
516
510
512
520
521
574
576
578
505
GSC
FLEET CONTROL MODULE/SHOW PROGRAM
570
572

FIG.5

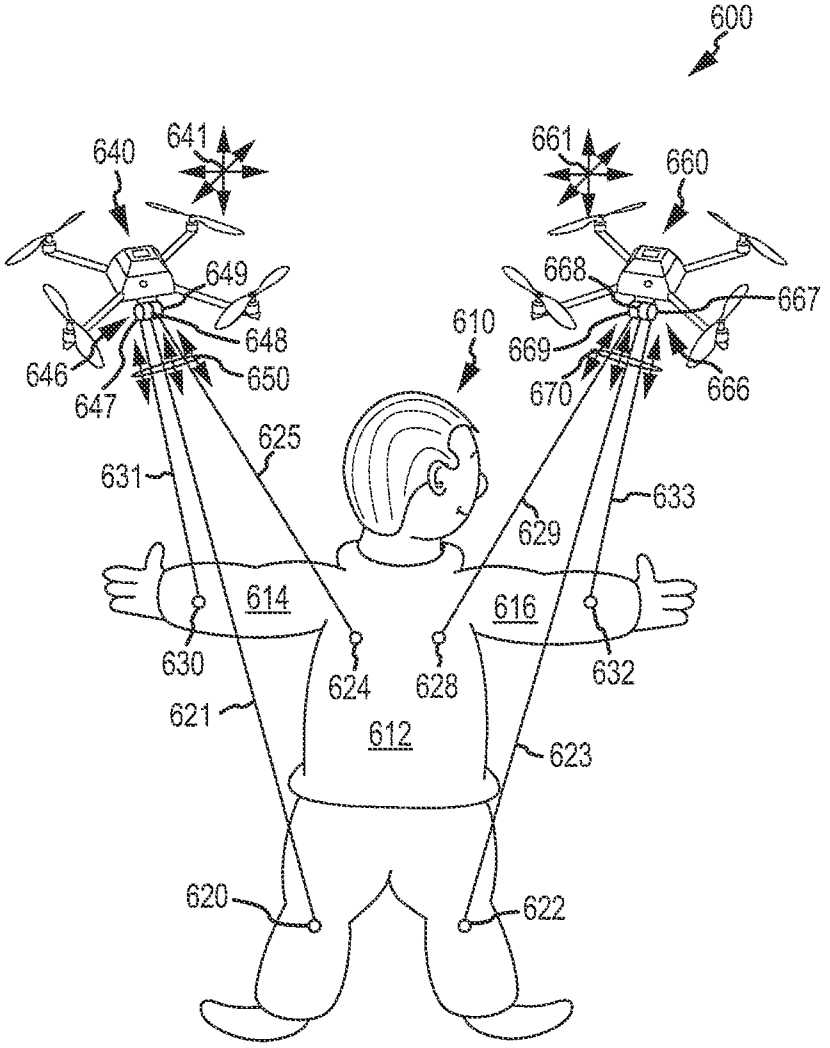

600
640
641
661
660
649
668
667
610
648
669
646
650
670
666
647
625
631
633
629
614
616
630
624
628
632
621
612
623
620
622

FIG.6

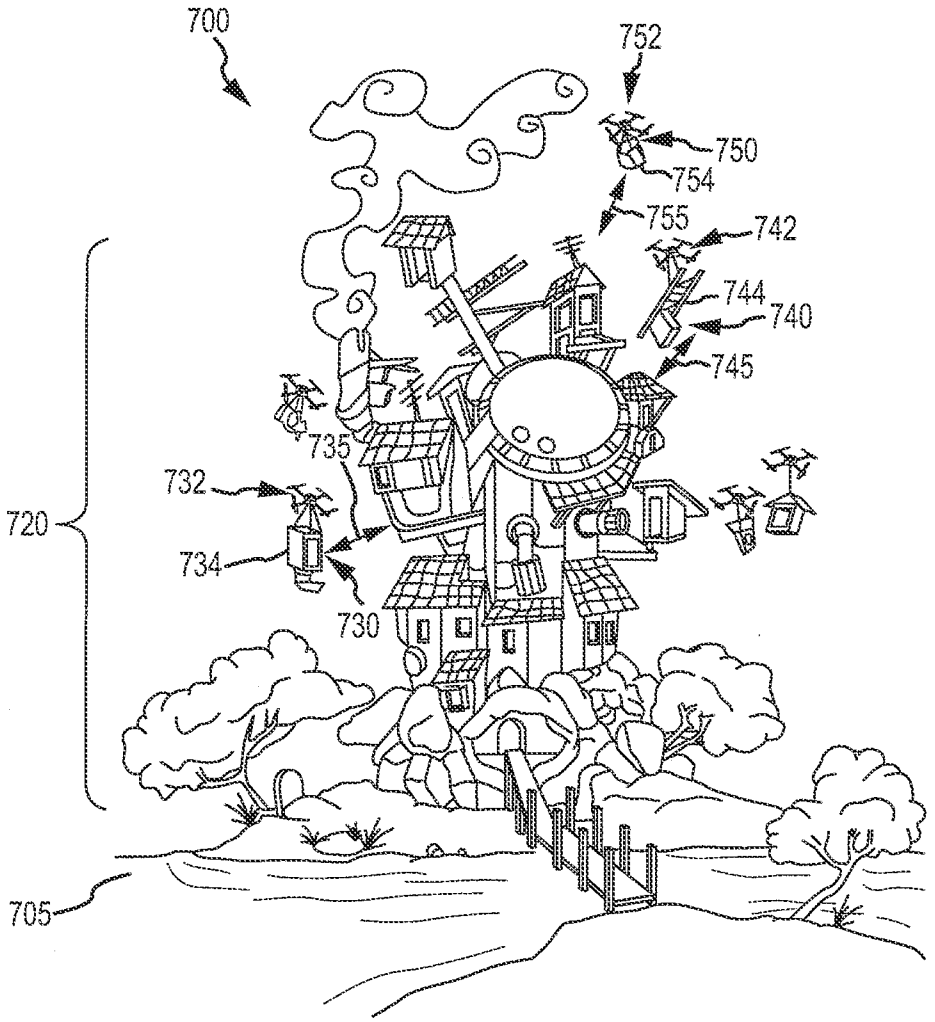


FIG.7

AERIAL DISPLAY SYSTEM WITH MARIONETTES ARTICULATED AND SUPPORTED BY AIRBORNE DEVICES

BACKGROUND

[0001] 1. Field of the Description

[0002] The present invention relates, in general, to aerial displays and control of unmanned aerial vehicles (UAVs) such as multicopters, and, more particularly, to an aerial display system (and corresponding control method(s)) providing aerial marionettes or puppets articulated and supported by UAVs.

[0003] 2. Relevant Background

[0004] In the entertainment industry, there are many applications where it is desirable to provide an aerial display. For example, an amusement park may have a lagoon or other open space over which it is desired to present a display to entertain visitors. In another example, massively large aerial displays may be presented at sport stadiums or other venues to celebrate holidays such as New Year's Day throughout the world and the 4^{th} of July in the United States.

[0005] While it is desirable to provide exciting and surprising shows, each large aerial display must also be presented in a safe manner. Further, for theme parks and other settings, it may be useful for the aerial display to be controlled and choreographed to be repeatable but adapted to be modified. For example, it may be useful to repeat a particular show for several weeks (e.g., during a particular holiday season) but then modify it to suit a new season or provide a differently themed show to attract repeat visitors.

[0006] Presently, aerial displays have been limited in how easy it has been to alter the choreography and to provide a repeatable show. Some "aerial" displays have relied upon very complex fountain systems to provide sprays of water upon which light may be projected or directed. These shows can be difficult to change or modify to provide a new show and are limited in the amount of the air space that can be utilized as the spraying water only reaches certain heights. Other aerial shows rely on fireworks, which can be dangerous to implement and often provide a different show result with each use. Other displays may us aircraft such as blimps dragging banners or even large display screens. While useful in some settings, these aircraft-based displays typically have been limited in size and use only a small number of aircraft and display devices.

SUMMARY

[0007] The inventors recognized that presently there are no mechanisms for creating very large aerial displays such as a display that is reusable/repeatable, dynamic, and interactive. To address this need, the following description teaches an aerial display system (and control method) that one or more large (e.g., blimp-sized) marionettes or string puppets, numerous unmanned aerial vehicles (UAVs) tethered to the marionettes via control/support lines (e.g., the marionette strings) linked to joints and/or the frames of the marionettes, and a ground control station for choreographing the movement of the UAVs to control movement of the marionettes (e.g., to provide puppetry or controlled movement of the marionettes/puppets) to provide a dynamic aerial display. While the aerial display system is described generally as providing marionette structures that are suspended, the term "marionette" may also be used to cover structures supported by the UAVs above the UAVs (i.e., not suspended).

[0008] The aerial displays described herein were designed and created because it was understood by the inventors that many characters fly in their stories (such as in a book or movie) but, prior to the inventors' aerial displays, it was typically not technically feasible to create a flying object that mimics the characters such as due to size, weight, dimensions, or other design challenges. The aerial displays allow a show designer to utilize a flying character in numerous environments. For example, the aerial display system may include a marionette that mimics a character but that is much larger than "true size" in order that the flying marionette can be seen by a large number of spectators. The aerial display systems also allow the UAVs to be selectively controlled, such as to follow a flight plan providing flock-type control over the UAVs, to provide articulation of the large, flying marionette. This is a significant improvement over prior flying characters, which typically were provided in the form of parade or other blimps/balloons filled with hot air or other gases and that had little and/or awkward articulation of any movable parts.

[0009] More particularly, a system is provided for performing an aerial display in a predefined display air space. The system includes a plurality of unmanned aerial vehicles (UAVs) and a ground control system with a processor executing a fleet manager module and with memory storing a different flight plan for each of the UAVs. The system further includes a marionette with a body and articulatable appendages attached to the body. The body and appendages are supported with tether lines extending between the marionette and the UAVS. Then, during a display time period, the UAVs concurrently execute the flight plans to position and articulate the marionette within a display air space. In some embodiments, the UAVs each is a multicopter, and each of the multicopters includes a local controller operating to move the multicopter through a series of way points defined by the flight plan associated with the multicopter.

[0010] In some applications, the marionette includes a plurality of connecting elements each attached to an end of one of the tether lines. In other cases, though, marionettes are supported above the UAVs or multicopters such as with hard rods (e.g., tether lines may be construed broadly to encompass strings or wires for below UAV support and stiffer rod or support elements used to hold a marionette or articulable object for connection point) located above the UAV or multicopter. Each of the UAVs may be attached via one of the tether lines to only one of the connecting elements. In other cases, though, each of the UAVs is attached via the tether lines to two or more of the connecting elements. In such cases, each of the UAVs may include a winch assembly for selectively adjusting a length of each of the tether lines to articulate the marionette during the display time period. In other embodiments, at least sonic of the connecting elements are coupled to an articulating frame on or within the body or the appendages of the marionette.

[0011] According to another aspect, the display system may include a second marionette supported by one or more of the UAVs. In such a display system, the flight plans may be configured to define flight paths causing the marionettes to be positioned in proximity in the display air space to form a floating superstructure. This superstructure may be assembled and disassembled to create a larger marionette that is articulated by movement of the UAVs and/or later disassembled to create a dynamic aerial display.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is functional block diagram of a multiple UAV system useful for implementing the flight control techniques described herein;

[0013] FIG. **2** is a functional schematic or block diagram of a system for use in providing flight management or flight control over two or more flying objects such as UAVs;

[0014] FIG. **3** provides a logic diagram fur the onboard logic running or provided for execution on each UAV such as part of a multicopter control panel/board;

[0015] FIG. **4** illustrates an exemplary aerial display system during operation to support and articulate an aerial marionette within a display air space;

[0016] FIG. **5** illustrates another aerial display system showing UAVs manipulating and supporting an aerial marionette via puppet frame elements in the arms and torso of the marionette;

[0017] FIG. **6** illustrates yet another aerial display system similar to the system of FIG. **5** but showing use of multiple control/support lines per UAV and a winch assembly for selectively adjusting the relative length of the control lines to articulate the supported marionette by moving the UAVs and also by moving the wires/lines (with or without UAV movement); and

[0018] FIG. **7** illustrates an embodiment of an aerial display system in which each "marionette" is supported and articulated by one or more UAVs is configured to be combined with a one-to-many other "marionettes" to form a larger marionette/display assembly, which can then be further moved about the display air space and/or articulated by the UAVs.

DETAILED DESCRIPTION

[0019] Briefly, aerial display systems (and corresponding control methods or operating techniques) are described that present large aerial marionettes. The support wires, lines, or rods for a marionette are tethered to one or more airborne vehicles. In a manner similar to hands holding a control frame of a string puppet, the airborne vehicles are moved, through a flight plan (or follow a flight path made up of a number of way points) to support and position the tether/connection points of the marionette to articulate or animate the character mimicked by the marionette.

[0020] The character's body (torso, head, and movable appendages/limbs) may be fabricated to be very light in weight with little or no structural frame other than the joints and frame portion used to allow support and articulation by the airborne vehicles. The body may mainly be formed from mesh or fabric sheets that are relatively easily permeable by wind. Alternatively, the body may be formed with a balloon or blimp-type sheet(s) that may be chosen to at least partially contain a gas such as helium to lighten the body or portions of the body of the marionette. In other words, these structures are formed with two subcomponents: a propulsion system (e.g., multiple UAVs) and a payload (e.g., a character), and these two subcomponents interact with tightly coupled control laws.

[0021] The suspension assembly for each marionette may be in the form of one wire or line per support vehicle used to support the marionette. In other cases, though, each airborne vehicle maybe tethered via two, three, or more lines to the marionette (e.g., to each of a marionettes fingers, to multiple points of a head, arm, or leg, or the like). These control/support lines may be on a frame underneath the vehicle to allow the relative lengths of the lines to be modified during operations or a winch or similar mechanism may be provided to selectively alter the relative lengths of the control lines. The relative and changeable lengths of the limes from a single airborne vehicle allow the single vehicle to better articulate the portion of the marionette that it supports in the display air space.

[0022] In some cases, each support wire/line is fabricated to include at least one break point that is weaker than the rest of the line such that a break in the line occurs in a planned way, e.g., when the vehicles fly too far from each other generating too much tension in the marionette body or its internal framework/tethering points. Precise positioning of the airborne vehicles, such as through differential GPS, inertial navigation, compass information, and onboard and/or offboard vision-based localization, may be used to execute the choreography (e.g., based on the vehicle-specific flight plans) of the marionette (and the character that it is intended to mimic). Further, the precise positioning is used to maintain a consistent pattern in some operating modes, even if failure of a multicopter or other UAV occurs as the system may be configured to adapt to the present number of valid UAVs in flight.

[0023] The flying objects or airborne vehicles may take many forms to selectively move a marionette within a display air space. However, in some embodiments, the flying object is a UAV, which may be a multicopter. In such aerial display systems, a multicopter is modified or used to carry a marionette via one or more control wires/lines. Further, the display system may be controlled so that each multicopter is aware of other multicopters in their vicinity and is also able to be controlled by flocking logic via a ground station. In this manner, the set of all multicopters may be considered a puppeteer for the supported marionette or string puppet. Significantly, each multicopter may be aware of other multicopters in the vicinity, and all are controlled by a centralized show controller (e.g., a fleet control module or show program running/executed on a ground control system (GCS) or ground station).

[0024] Since a plurality of multicopters may be used to implement an aerial display system, it may be useful to first discuss a control method and system (or multiple UAV systems incorporating such control methods/systems) for use in controlling a flock of UAVs numbering 2 to 10 or more UAVs (e.g., 10 to 100 or more multicopters). This discussion of a control method may then be followed by specifics on particular implementations of aerial display system that may or may not use multicopters and its control method for such a large number of UAVs to act as a puppeteer for a large aerial marionette.

[0025] Briefly, the control method uses hierarchical-based supervisory control with multicasting techniques along with adaptive logic including onboard or local control modules provided on each UAV to adjust flight paths to safely avoid collisions based on communications with nearby UAVs. The result of the described control of the multiple UAVs in an airspace such as over a theme park or stadium is a flocking behavior in which the UAVs appear to move in a synchronized manner with movements that are not completely independent nor completely centrally controlled. The control method may be implemented in a system with four general components or pieces: a fleet management station (or ground station); flying objects or UAVs; at least dual-path communications between the ground station and the UAVs (e.g., much of the description below highlights use of dual-channel communication but

some embodiments may use three or more transceivers onboard a UAV (such as to provide a front channel (supervisory), a back channel (autonomous), and a show channel (lighting, payload actuators, and so on); and stage/show management. These four components or aspects of the control method/system are described below with reference to the figures.

[0026] First, with regard to dual-path communications, FIG. **1** illustrates a system **100** that may be used to control flying objects in a safe and repeatable manner. The system **100** includes a ground station or fleet manager **110** along with a plurality of multicopters (or UAVs) **130**, with each being implemented (as shown via arrow **137**) with the configuration of multicopter **150**. As shown, the fleet of multicopters **130** is configured for inter-UAV or multicopter communications **135**, and, as explained below, this intercommunication allows the multicopters **130** to safely react to a determination that another multicopter **130** is in a close proximity to avoid collisions while generally remaining on a predefined flight path. During runtime, ground station/fleet manager **110** is used for sending commands to maintain show performance and quality and to monitor safety information. During non-runtime, it uploads the show requirements.

[0027] Dual-path communication between the ground station **110** and the multicopter **150** is provided by each flying object or multicopter **150** having two communication channels shown at **117** and **119** in FIG. **1**. To this end, the ground station **110** includes a front-end radio or transceiver **116** and a back end radio or transceiver **118**, and the multicopter **150** also has two radios **154** and **156** configured for communicating **117**, **119** with the station radios **116**, **118**. Some embodiments may further include a show radio or transceiver **190** in the ground station **110** that communicates over show channel **191** with a radio/transceiver **194** on the multicopter **150**. The first or front end channel **117** provides a high speed communications channel (e.g., 2.4 GHz or the like) that is useful to provide choreographed movement of the multicopters **150** (e.g., When the UAVs **130** are not simply following a flight path but have time-synchronized movements from position to position in an airspace).

[0028] For example, the front channel **117** may be thought of as a robust, low-bandwidth "primary" channel for synchronized motion control and manual override control by the ground station. The back channel **119** may be thought of as a "secondary" high-bandwidth channel. The back channel **119** may be used for transmitting telemetry from the multicopter **150** to the ground station **110**, for the ground station **110** to transmit signals for supervisory control of the multicopter **150**, and for a back up communication channel should the front end channel **117** fail to one or more of the multicopters **150**. Further, the show channel **191** may be used for non-flight-related communications.

[0029] The ground station **110** is shown to include a processor(s) **112** that runs software to perform the ground station control functions discussed herein such as the fleet manager module **114**. The processor **112** controls operations of the radios/transceivers **116**, **118** including managing memory **120** to store data received from the multicopter **150** over channel **117**, **119**. The memory **120** is shown to store flight paths **122** that may be downloaded or provided over front end channel **117** to the multicopter **150** (of those in fleet **130**) for use by a local control module **160** to control movement of the multicopter **150** (e.g., via selectively throttling of motors turning one or more of the rotors). The memory **120** also stores a set or file of data **124** for each multicopter **150** of a fleet **130**, and the data **124** may include an expected state **126** for the multicopter **150**, an actual state **127** of the multicopter **150**, and other telemetry data **128** (which may be passed via the back end channel **119** to the ground station **110**).

[0030] Each multicopter **150** is shown to include one or more processors **152** that control operation of the two radios **154**, **156** so as to process received data/signals on channel **117**, **119** and to, as appropriate, store data in onboard memory **170**. The processor **152** also may run or execute code, programs, or software such as a local control module **160** to function to perform the UAV-control functions described herein. The memory **170** may be used to store a flight path **174** provided by the ground station **110** and to also store determined positions and telemetry data **178** (that may be provided to the ground station **119** as shown in memory **128**). The telemetry data **178** may include a heartbeat (each UAV in fleet **130** indicates to the ground station that is operational or "alive"). The telemetry data **178** may further include a present position of the multicopter **150** (e.g., a three dimensional location in the airspace) and the present speed of the multicopter **150**. Further, the telemetry data **178** may include the health of any monitored components on the multicopter **150** and a battery life/status as well as other monitored data.

[0031] The fleet management component or module **114** acts to monitor the expected state **126** and the actual state **127** each Of the flying objects **150**. For example, the module **114** may compare a present position or traveling speed of a multicopter **150** with its expected state **126** (which may be defined by a flight path **122** or a choreographed and time-synchronized movement of UAVs **130** such as in a light or other aerial display/show). Based on this monitoring, the fleet management module **114** may make adjustments such as using the following priorities: localization (e.g., position of the multicopter **150** with respect to other UAVs/multicopters); environment (e.g., to adjust for high wind conditions or the like); safety (e.g., return the multicopter **150** to a safe location or operating mode if it or other UAVs are not operating as expected); show performance (e.g., adjust position, speed, or other operating parameters to meet show needs); fleet status; and operator convenience/performance needs.

[0032] As discussed above, the fleet management module **114** and local control module **160** are configured to work together to provide flocking-type control. In use, the inter-UAV communications **135** are used to allow operational data to flow or spread hierarchically among the UAVs **130** rather than relying upon centralized/ground control alone. In other words, the fleet management module **114** provides a level of centralized control or central logic that acts to control the movement of the UAVs/multicopters **130** such as by providing flight paths **122** and/or making real time adjustments based on a comparison of expected state **126** and actual state **127** (or for safety reasons). With regard to inter-UAV communications, it may be useful to note the following: (a) some units may be designated as master nodes talking with the fleet manager; and (b) the master nodes may operate to send out in-flight calculated information or commands to remaining UAVs.

[0033] The movement/control is not swarm-based control in part because swarming UAVs can collide or have an inherent lack of safety and because the system **100** is designed to avoid random movements as want a flock or synchronized movements among the multicopters **130**, **150**. However, the inter-UAV communications **135** as processed and generated

by the local control module allows each multicopter **150** to react safely to environment conditions such as increasing or direction-changing wind and presence/movement of neighboring multicopters **130**, **150** as crossing flight paths is allowed in the system **100** (e.g., may be required by flight paths **122**). In other words, the onboard logic **160** acts to control the multicopter **150** movements so as to avoid collisions while attempting to stay generally on the flight path **174**.

[0034] FIG. **2** illustrates a system (or a flight management control system) **200** for use in managing or controlling UAVs to provide an aerial vehicle flock with synchronized flight. The system **200** is shown to be made up of or include components used to perform off-line activity at **202** and used to perform on-line activity at **204**. The off-line activity **202** may include designing or selecting a show concept or choreographed movement **204** for a plurality of UAVs to achieve a particular effect or perform a task(s).

[0035] The show concept (e.g., digital data stored in memory or the like) **204** may then be processed with a computer or other device to simulate as particles with spatial boundaries as shown at **206**. For example, each multicopter to be used to provide an aerial display or show (or to perform an aerial task) may be modeled as a particle, and a three dimensional space such as a sphere with a predefined diameter may be used to define a safety envelope for that UAV or flying object. The safety envelope or space is used to reduce the risk of a collision between to UAVs (e.g., create and choreograph a show to avoid collisions and not allow two UAVs to have their safety envelopes intersect/overlap as the UAVs move along their flight paths).

[0036] The created show or task for the multiple UAVs is then exported to memory or other devices as shown at **207** for processing, with this "show" typically including a file per each UAV or unmanned flying object, Each of these files is processed to generate real world coordinates for each UAV to be achieved over time during a show (or performance of a choreographed task(s)). This processing creates individual flight plans **208** for each UAV, and. such processing or generating of the flight plans **208** may include processing the modeled show **207** based on specific logistical requirements. These requirements for example may modify a show to suit a particular venue (e.g., is the air space the same size and shape as in the simulation and, if not, modification may be useful to change or set real world coordinates for one or more of the UAVs).

[0037] The logistical requirements may also include setting a ground truth for the venue and adding safe or "home" points (e.g., with GPS or other location settings) where each vehicle can be safely positioned such as at the beginning and end of a show or when a safety override is imparted (e.g., "return to home"). The stage/show management component **202** may be considered a component that translates central show controller commands, which may be a foreign system, to fleet actions that are sent **209** to the fleet management component either through scripts (e.g., data files), real time computer messages, and/or hardware triggers.

[0038] At **209**, the flight plans are provided to the ground station **210** (or ethereal fleet controller/computer or ground control system (GCS) as used in FIG. **3**). The system **200** further includes a number of UAVs **220** shown in the form of multicopters in this example. The multicopters **220** may be in groups/sets with set **222** shown to include two copters **223**, set **224** including one copter, and set **226** includes four copters. These sets may act or function together, at least for a portion of a show or flight path, to perform a particular display or task.

[0039] In other cases, all of the multicopters may be considered part of large set that moves as a flock or otherwise has its movements time synchronized and/or choreographed by flight plans **208**. As shown at **229**, a multicopter **228** in the group **220** can communicate with its nearby or neighboring multicopters so as to determine their presence, to determine their proximity, and when needed, to process the flight plan, determined neighbor position, and other environmental data to modify their flight plan to avoid collision and/or communicate **229** with the neighboring multicopter to instruct it to move or otherwise change its flight plan/movement to avoid collision.

[0040] As discussed with reference to FIG. **1**, the system **200** also includes two communication channels between the GCS **210** and each of the multicopters **220**. The front end channel is shown at **212** with the GCS using remote control radios or wireless transceivers **214** to communicate data/control signals **215** to each of the multicopters **220**. In this manner, the GCS or receiver **210** binds to multiple aircraft so as to allow multicasting of control signals such as to wirelessly flight plans **208** to each of the multicopters **220** before flight operations are initiated by the GCS **210**.

[0041] In some cases, a manual override (selectable switch, for example, on each radio **214**) **216** is provided to allow an operator to signal **215** a particular multicopter **220** to switch to safe mode (e.g., to return to home, to safely drop to ground, and so on). The back end channel for communications is shown at **230** with each of the multicopters **220**, which may have two or more radios as discussed with reference to FIG. **1**, communicating telemetry or other data (e.g., GPS and altitude data via a mesh network) to the GCS **210** as shown to be relayed **233** via a wireless transceiver device **232** (e.g., with a range when working with UAV radios of about 1 mile). Each multicopter **220** may include a unique identifier or ID with their telemetry data (e.g., the same ID as used to associate a flight plan **208** with a particular multicopter **220**).

[0042] In system **200**, each of the flying objects **220** may be a multicopter that optionally may be modified to carry a variety of payloads (or units). For example, the payload may be one or more lights sources. The payload may include the communication devices, e.g., two or more radios discussed herein, to provide multiple communication channels. Any communication channel may be linked to the GCS **210** (or its fleet management module discussed above with reference to FIG. **1**). In one implementation, the multicopters **220** were each modified via software (e.g., local control module **160** in FIG. **1**) to provide all the logic (e.g., see FIG. **3** and corresponding discussion) required for operation in a show environment including flocking logic, safety strategies, light show scripts, character expression logic, and alternative show maneuvers.

[0043] FIG. **3** illustrates a flowchart or logic diagram of a safety control method or logic **300** that may be implemented on board each multicopter or flying object (e.g., via the local control module **160** as shown for a multicopter **150** in FIG. **1**). In the safety process **300**, a process loop begins at **302** and a first step may be to perform a check of the front end communication channel at **304**. At **306**, the process **300** continues with determining whether the front channel is still up/available or is now down. If determined at **306** to be down, a flag is set at **308** indicating the front end communication channel has failed as shown at **312**.

[0044] At this point, the process **300** may continue at **310** with controlling the multicopter in a failsafe mode as shown at **310**, and this may involve having the multicopter loiter or hold its present position for a preset period of time, until the front end channel is available (as determined by repeating step **304**), or until instructed otherwise by GCS user action **350** (e.g., an operator may identify a loitering multicopter in the group/flock and instruct it to take certain action such as to return to home (RTH)).

[0045] The process **300** may include an emergency stop cycle or subroutine **320**. In the stop cycle **320**, an ongoing (frequent periodicity) step **340** a heartbeat of the multicopter may be performed. In this step **340**, the logic/processor onboard may transmit an "alive" pulse/signal to the GCS and also determine its present position and other telemetry, which is also transmitted to the GCS via the back end communication channel. As part of step **340**, a check is performed to determine a status of the back end channel to the GCS. The following are examples of multiple modes of failure that may result in different reactions: (a) show failure (e.g., missed waypoint) to which the system may respond by adapting to stay safe and continue flight; (b) front channel communication failure to which the system may respond by going to autonomous mode to stay safe and possibly cancel a show if needed; (c) back channel communication failure to which the system may response by waiting for confirmation and hold in place until communication is reestablished (if not, then land); and (d) full communication failure to which the system may respond by landing in place.

[0046] After step **340** is performed, the method **300** continues at **318** with a determination of Whether or not the back channel is down. If not, the method **300** can continue at **319** with a determination of whether or not the front channel flag **312** is set. If not, the method **300** can return to perform another loop **302**. If the front end flag is set at **312** (fail is true) as determined at **319**, the method **300** may continue at **358** with waiting for a control signal or action to be performed by the GCS (e.g., an operator uses the GCS to transmit a control signal). At **356**, a determination is made regarding a timeout after a preset period of time.

[0047] If the timeout period has not elapsed, the method **300** continues at **352** with processing of a GCS action that is provided by wireless signal/transmission **351** from the GCS **350**. A user or operator may provide input at a ground station or GCS to perform a user-initiated emergency stop, which is checked for at **354**. If an e-stop is not issued in the transmission **351** as determined at **354**, the method **300** may continue at **352** with further processing of the action **350** such as to determine that instructions have been. received to operate the multicopter in a particular manner.

[0048] These responses/actions are shown at **360** with the local/onboard control logic acting to land the multicopter, to return the multicopter to home, to hold the present position (but changing altitude is allowed), to hold altitude (but wind or other environmental conditions may cause position to change over time), or other action. This step **360** is followed with a new control/safety loop **302**. In this manner, a user can provide at **350** override or direct control signals to each multicopter that can override a program/flight plan at any time or in response to loss of the front end communication channel. When a timeout period has elapsed at **356**, the e-stop cycle **320** may be performed. In particular, the onboard logic may act to land the multicopter as shown at **330** if no GCS action is received within the present time (e.g., 10 to 30 seconds or the like).

[0049] The e-stop cycle **320** may also be initiated when it is determined by the onboard control logic at **318** that the back end channel is down. In such a case, step **322** is performed to check the IMU and then determine at **324** whether the pitch or roll angle is greater than some preset acceptable limit (e.g., 15 to 30 degrees or more). If this pitch is not exceeded, the e-stop cycle **320** continues at **330** with landing the multicopter. If the pitch or roll angle is greater than the preset maximum at **324**, the e-stop cycle **320** continues at **326** with stopping the motors and otherwise "disarming" the multicopter to place it in a disarmed state at **328** (at which point the multicopter will fall to the ground rather than gently landing as is the case at **330**).

[0050] With the above discussion and general discussion of a flight control system (system **100** and **200**) understood, it may be useful to more specifically discuss functions of particular components of such a flight control system and the onboard logic and controls of each multicopter or other with regard to the ground control system (GCS), the GCS controls preflight, show state, and safety.

[0051] During preflight, an operator uses the GCS to load a flight plan onto each UAV (e.g., transmitted wirelessly via the front end channel for storage in memory accessible by the local control module of the UAV). During a show, the GCS and its fleet manager module acts to run the flight plan previously loaded on the UAV. This "running" may involve an operator using a trigger module or mechanism of the fleet manager module to say start or "go" to initiate all the multicopters or UAVs to begin to run a flight plan. Typically, before this step, each UAV is placed at a ground location for takeoff or at an aerial home position, with these home or start positions being included in the overall flight plan for a show or to perform a task as a flock of UAVs.

[0052] During the show, the GCS actively monitors safety and an operator can initiate a GCS user action as shown in FIG. **3**. More typically, though, the GCS monitors the operation of all the UAVs in the flock by processing the heartbeat and telemetry data provided by each of the UAVs via the back channel communications from the back end radio or, transceiver provided on each UAV. In some embodiments, the fleet manager module has software/logic that compares the actual state of each UAV against the expected state at that particular time for the UAV according to the presently enacted flight plan.

[0053] If the actual state does not compare favorably (e.g., the position of the UAV is outside an acceptable range such as several-to-many feet off course), the fleet manager module may generate an alert (audio and/or visible) on a GCS monitor or other linked device to warn an operator of this possibly unsafe condition. At this point, the warned operator may take action (user action in FIG. **3**) to correct the operations of the UAV(s) or to instruct the UAV to return to home or take other actions.

[0054] For example, the fleet manager module may allow the operator to select or "hit" a safety button (or selectable icon), and the fleet manager module would communicate via the front end or back end communication channel to instruct the UAV to go into a predefined safety mode of operation (e.g., see box **360** of FIG. **3**). This safety mode instruction or GCS is processed by the local control module on the UAV, with the UAV drive system correspondingly operated to posi-

tion the UAV in a safe location or mode of operation. Such a safety mode/operation can be issued on a per UAV basis or to the entire flock concurrently (or even to a subset of such a flock). In some embodiments, the fleet manager module actively negotiates with each UAVs local control module (or its subroutine handling sate operations); in other words, hitting the "safety button" on the GCS does not necessarily require the affected UAV to immediately take action as the UAV control system may act to complete a task or first attempt a control adjustment to correct its operations prior to allowing GCS override (such as causing the UAV to return-to-home).

[0055] After the "go" or start signal is issued by the fleet manager module/GCS upon an operator input, the GCS along with the local control software/hardware on each UAV work to safely perform the preloaded flight plan/show. As discussed above, the control. method and system taught herein combines centralized control (e.g., to allow manual override for safety or other reasons during a show/flight-based task) with smart UAVs to more effectively provide flock-type movement of the UAVs. In other words, the UAVs may each be given a particular flight plan that they work toward over time (during a show time period) while attempting to respond to environmental conditions such as changing wind or the unexpected presence of another UAV within or near to their safety window (or safe operating envelope surrounding each UAV such as a sphere of several-to-many feet such as 10 to 30 feet or the like in which no other UAV typically will travel to avoid collisions).

[0056] During operations, the GCS is used to trigger each of the UAVs to begin their stored flight plan starting from a home or show/task start point (e.g., each UAV may be placed at differing launch points or be hovering/flying at a particular ground point at a predefined start altitude). In some cases after the "go" is received by a UAV, each UAV uses its local control module (or other software/programming) to attempt to follow the flight plan but with no time constraints. In other words, the flight plan may define a series of earth points or way points along with elevation/altitude values for the UAV. In these embodiments, the UAV is controlled in a relatively fluid manner and not tied to accomplishing tasks in a certain amount of time (e.g., the flight plan does not require the UAV be at a particular location at a particular time after the go signal is received).

[0057] In some implementations such as those using multicopters for the UAVs, the flight plan is built up assuming that each UAV travels at a preset and constant flight speed. This flight speed may be set independently for each UAV or may be the same (or within a relatively small range) for each of the UAVs. In other cases, though, the local control module may be adapted to adjust the flight speed to suit the environmental conditions.

[0058] For example, stronger winds may make it beneficial to speed up (or at least operate rotors of a multicopter) when moving against a strong head wind and to slow down when moving with the strong tail wind. The speed of the wind may be determined at the UAV with the local control module and sensors provided as part of the payload or the wind direction and speed information may be provided by the GCS to each of the UAV. In some case, flock control is preferred such that each UAV has its speeds adjusted commonly, e.g., each UAV runs at like flight speeds while moving in a like direction so as to appear to have synchronized and non-random movement.

[0059] In some embodiments, each UAV acts independently to try to continue to follow its own flight plan. Each flight plan differs at least in the fact that each UAV begins at a differing start point or home and moves toward its first way point. To this end, each UAV is equipped as needed to determine its present three dimensional position that includes a latitude/longitude position (e.g., a GPS position or similar position data) along with its present altitude or height above the ground. The local control module uses this present position data to determine modify (if necessary) its present direction or heading to continue to move toward the next way point in its flight plan. This may involve changing it course and also its angle of attack to reach the desired height at the way point.

[0060] Generally, the GCS monitors for safe operations of the UAVs as discussed with reference to FIG. **3**, but an operator may take steps to manually override a particular one of the many UAVs to provide better control of that UAV. For example, the fleet control module of the GCS may operate to compare an expected position of the UAV with its actual position (provided via back end channel in its telemetry or other data). A warning may be provided in a GUI that the UAV is trending of course or is outside an accepted tolerance for reaching its next way point.

[0061] For example, the GUI may show properly operating and positioned UAVs in green, UAVs that are off course or out of position a safe amount in yellow, and UAVs outside of a safe envelope in red. The red/unsafe UAVs may be handled automatically or manually to cause them to enter a safe mode of operation (return to home, for example). The yellow UAVs that are operating outside of desired conditions, though, may be manually operated to try to assist them in returning to their flight path such as by manually changing speed, direction, angle of attack, or the like to more quickly bring the UAV to a desired way point. After manual operations are complete, the control may be returned from the GCS to the local control module for local control of the UAV based on the flight plan stored in its memory. Note, the GCS may be configured to evaluate collision issues and execute collision avoidance commands to preserve show quality (i.e., flight performance) in degrading weather conditions.

[0062] In other embodiments, a local control module of a UAV may operate to adjust the flight plan during flight to better react to environmental conditions (such as gusts of wind that may throw it, at least temporarily, off course). For example, a flight plan may provide a time relative to a start time (when "go" was signaled by the GCS to the UAVs) to reach each of its way points on the flight plan. One embodiment may call for the UAV to determine a distance to a next UAV and its present estimated time of arrival (e.g., using changes in its earth position to determine its true speed or rate of travel). If the time of arrival is not within a window about a preset/goal arrival time, the local control module may act to increase the flight speed of the UAV such as by increasing the rate of rotation for the rotors of a multicopter. Likewise, if the UAV is moving too quickly (e.g., strong tail wind), the UAV's local control module may act to slow the flight speed. In this manner, the movement of the UAVs may remain better synchronized to provide a flock control.

[0063] In other cases, though, the local control module of the multicopter or other UAV acts to determine whether or not a way point was reached within a predefined time window, with the flight plan defining times for being at each way point relative to a start/go time. If not (e.g., did not reach a way point at Time "X" plus an allowable delay), the local control mod-

ule may act to modify the flight plan by directing the UAV to skip the next way point and fly directly to the way point following the next. For example, a flight plan may include way points A to Z. If a local control module determines that a predefined time window, for way point C was not achieve, the local control module may skip or remove way point D from the flight plan and cause the UAV to take a direction/course (e.g., a straight line or other predefined path) to way point E. In this way, the flight speed is maintained (e.g., all UAVs fly at the same speed) while allowing the UAV to "catch up" if they fall behind their flight plan (e.g., defining a set of way points or earth points to pass through or nearby within a predefined time period that may correspond with a time to perform a show/display or perform a task with the multicopters).

[0064] With regard to safety and monitoring of operations, each UAV may store a definition of a geofence that defines an outer perimeter (and an inner area in some cases) or boundary of a geographical area. The UAV's local control module compares the present position determined for the UAV during a flight and compares this position to the geofence. If this boundary is crossed (or is being approached such as within a preset distance from the geofence, the local control module may act to promptly return the UAV back within the geofence boundaries. In other cases, the UAV may be switched into a safe operating mode (as discussed with reference to FIG. **3**), and this may cause the UAV to return-to-home or otherwise safely return to ground (or other safe holding position). For example, the geofence may define the boundaries of a lagoon or stadium field, and the UAVs may fly over this geographical area (or within, an area offset from the physical boundaries of this area to define a somewhat smaller area) but not outside it so as to avoid flying directly over any people in an audience to provide enhanced viewing safety.

[0065] Further, regarding safe UAV operations, some embodiments of flight control method and system involve configuring the UAVs to have UAV-to-UAV (or multicopter-to-multicopter) communications or other technologies provided onboard to avoid collisions without reliance upon the GCS to intervene. Each UAV may use its local control module to operate on an ongoing basis to detect when another UAV comes within a predefined distance from the LAN such as within a sphere of 10 to 30 feet or the like. The first UAV to detect such a condition (or both UAVs if a tie) generates a collision warning message and transmits this message to the offending/nearby UAV to alter its course or present position to move out of the first UAV's air space. For example, the UAV receiving such a collision warning message may store an evasive action in its memory and initiate this action (a fixed movement such as angling to the right or left a preset angle). The evasion may be taken for a preset time period and then the UAV may return to following its flight plan (e.g., recalculate a course to the next way point from its new present location or the like).

[0066] As discussed with regard to FIG. **3**, the local control module of each UAV may perform other functions to control its own flight to ensure safe operations. For example, the local control module uses a front end radio and a back end radio to communicate with the fleet manager module of the GCS. The status of these communication channels is monitored by the local control module, and, when either communication channel is detected to be lost (e.g., an expected receipt confirmation from the GCS is not received to a transmission of a telemetry data by a UAV), the local control module may react to this loss of communication by entering a safe operating mode (e.g., land, return to home, hold position, or the like).

[0067] In another example, the UAV's local control module monitors the present orientation and/or altitude of the UAV and if the orientation is outside an acceptable range (e.g., pitch or roll exceeds **20** degrees or the like for a multicopter) or if the altitude is too high or too low, the local control module may also act to enter the UAV into a safe operating mode (before or after attempting to correct the operating problem).

[0068] With the above understanding of control of UAVs understood, it may be useful to again turn to a discussion of aerial display system used to provide aerial puppetry or a large-scale string puppet (or marionette) show using UAVs. For example, FIG. **4** illustrates an exemplary aerial display system **400** during operation to support and articulate an aerial marionette **410** within a display air space over an audience of spectators **408** standing or located on the ground **405**.

[0069] The marionette or string puppet **410** includes a body **412** and a number of articulatable (or selectively moved or positioned) appendages or elements such as a head **414**, an aim **416**, a leg made up of an upper portion **418** and a lower portion **419**. These may each be fabricated of lightweight materials and include a frame and may be configured for low wind resistance or, alternatively, be adapted for containing a gas such as helium to lighten each of these portions to reduce the force required to support and move the components of the marionette **410**). Also, the connection of the head **414**, arm **416**, and upper leg portion **418** to the body **412** may be such that each may move, rotate, or pivot relative to the body when articulated by their supporting UAVs. To this end, FIG. **4** illustrates that the aerial display system **400** may include a large number (e.g., 10 to 100 or more) UAVs that would be controlled as discussed above by a GCS not shown in FIG. **4** but shown in FIG. **1**) and also through onboard logic as well as UAV-to-UAV communications (as discussed above for safety purposes and as discussed would be understood as being useful for maintaining show quality while using UAVs as puppeteers for the marionette **410**).

[0070] As shown, a UAV **420** is linked via control or support wire/line **422** at a tether or connection point/element **423** to the marionette head **414**. With movement of the UAV **420** based on a show program/flight plan, the control line **422** moves or tensioned in a particular direction and to a certain amount. This causes the head **414** to be positioned in the air space above the ground **405** and to be articulated as desired to cause the marionette **410** to be animated or to mimic a character (e.g., to turn the head **414** to face one portion of the audience **408** and then another portion or to move up and down while talking or singing and so on).

[0071] To position and articulate the arm **416**, the UAV **430** is shown to tension and move **434** connecting line **432**, which is attached at an end to the tether or connection point/element **433** to the arm **416**. As the UAV **430** follows its assigned flight plan to a number of way points in the display air space, the arm (or forearm) **416** is positioned and articulated as it is supported by the UAV **430** at point/element **433**. Similarly, the upper leg **418** is positioned and articulated by the UAV **450** via connecting or supporting line **452** that is attached to the UAV **450** and to the leg **418** at tether or connecting point/element **453**. During operation, the UAV **450** moves along its flight plan, which results in the line being moved and tensioned in a certain direction and amount, respectively, as

shown with arrow **454**. This causes the tether point **453** to move so as to support and articulate the upper leg **418**.

[0072] Further, another UAVs **440** is used to move and apply tension to (shown with arrow **114**) support or connecting line **442**. This line **442** is attached to the lower leg portion **419** at tether or connecting point/element **443**. Hence, when the line **442** is moved **444**, the tether element **443** moves or is articulated (in any direction as shown with arrows **445**) so as to move the lower leg **419** (e.g., to cause the marionette to walk, kick, dance, and so on). The movements **424**, **434**, **444** of the connecting or supporting lines **422**, **432**, **442** is coordinated and controlled with the concurrent execution of the flight plans by the UAVs **420**, **430**, **440**, **450**, which may be thought of as working as a team or flock to provide puppeteering of the marionette **410** (which may be quite large such as 40 to 100 feet or more in height).

[0073] In the display system **400**, the marionette **410** was supported and articulated tether or connecting points/elements at particular location within or on the exterior of the marionette **410**. However, as with conventional string puppets or marionettes, it may be desirable to support and articulate the marionette with UAVs that are attached via a line or wire to an articulation or frame member on or within the body/appendages of the marionette.

[0074] With this in mind, FIG. **5** illustrates an aerial display system **500** with a marionette or string puppet **510** that has a body **512** and articulatable appendages/limbs **514**, **516**. Within or on these marionette components, one or more articulation frames or members are included to provide UAV attachment and tether points that better support and allow lifelike (or other desired) movement of the marionette **510**.

[0075] Particularly, the marionette **510** includes a first articulation frame **520** with a tether point/element **521**. on or within the back or torso **512** of the marionette **510**, a second articulation frame **522** with a tether point/element **523** on or within the left arm **514** of the marionette **510**, and a third articulation frame **524** with a tether point/element **525** on or within the right arm **516** of the marionette **510**. The body frame **520** is shown to be triangular and planar in shape but other shapes may be used while the frames **522**, **524** are both shown to be linear or elongated tubes, rods, or shafts (again, though, the shape of the frame may be altered to practice the system **500**). The frames **520**, **522**, **524** may be formed of rigid or somewhat flexible materials such as metals (e.g., aluminum) or plastics.

[0076] With the use of the frames **520**, **522**, **524**, lifting and movement of the frames **520**, **522**, **524** cause a larger surface or portion of the marionette **510** to be lifted and moved/articulated. This acts to better conceal the tethering or connecting points **521**, **523**, **525** and/or articulates the marionette **510** in a more lifelike or desired manner. To each of the connecting points **521**, **523**, **525** is attached a connecting line/wire or tether **530**, **532**, **534** that may be pulled selectively moved and tensioned (or not tensioned.) as shown with arrows **531**, **533**, **535** so as to support and articulate the marionette **510** in a display air space over the ground **505**.

[0077] A set or team of UAVs (multicopters, for example) **540**, **550**, **560** are provided in the display system **500** and attached to the opposite ends of the tethers or lines **530**, **532**, **534**, respectively. When the UAVs **540**, **550**, **560** move in various directions as shown with arrows **541**, **551**, **5610**. the lines **530**, **532**, **534** move **531**, **533**, **535**, which positions and articulates the marionette **510** by articulating the body **512** via frame **520** and connecting point **521**, the arm/limb **514** via frame **522** and connecting point **523**, and the arm/limb **515** via frame **524** and connecting point **525**.

[0078] As discussed above with regard to FIGS. **1-3**, a GCS **570** may be provided that executes a fleet control module/show program **572** so as to control movement of the UAVs **540**, **550**, **560**. Particularly, the GCS **570** may wirelessly communicate (as shown with arrows **574**, **576**, **578**) with the UAVs **540**, **550**, **560** prior to the show to download a flight plan and during a show to, for example, provide safety-based commands or override/correction commands to move the UAVs in the display air space.

[0079] As shown, the three UAVs **540**, **550**, **560** may be executing, via local control and communication with the other UAVs **540**, **550**, **560**, the flight plan assigned to each by the fleet control module **572**. This may involve each UAV **540**, **550**, **560** moving as a flock (choreographed manner) to a number of way points along a flight path associated with each UAV **540**, **550**, **560**. The movements **541**, **551**, **561** of each UAV **540**, **550**, **560** causes the tether or connecting lines **530**, **532**, **534** to move **531**, **533**, **535**, which articulates the marionette such as to mimic movement of a particular character as part of a puppet show.

[0080] FIG. **6** illustrates an aerial display system **600** with a marionette **610** that is supported and articulated via a plurality of tether or connecting points/elements positioned on (or within) its exterior surfaces. As shown, the marionette **610** includes a body/torso **512** with two connecting/tether points or elements **624**, **628**, arms **614**, **616** each with a connecting point/element **630**, **632**, and legs each with a connecting point/element **620**, **622**. Each of these connecting elements is attached to a first end of a tether or connecting line **621**, **623**, **625**, **629**, **631**, **633**.

[0081] In the system **500**, a UAV was provided for each tether or connecting line. In system **600**, however, each UAV is used to support and articulate the marionette **610** at two or more connecting elements/points. Particularly, in the illustrated example of FIG. **6**, a first UAV (e.g., multicopter) **640** and a second UAV **660** are provided that may be selectively positioned as shown by arrows **641**, **661** (e.g., to follow a flight plan defining their concurrent movement to a number of show way points and/or based on control from a GCS, not shown in FIG. **6**). Each UAV **640**, **660** is connected to two or more of the tethers with UAV **640** connected to tethers **621**, **625**, and **631** and UAV **660** connected to tethers **623**, **629**, **633**. The use of a single UAV to support and move two or more connecting points/elements of the marionette **610** results in a different articulation of the marionette than use of one-to-one relationships between connecting points and UAVs.

[0082] Further, the connections at the UAVs **640**, **660** with the lines may be fixed so as to provide a single length of the tethers or connecting lines (e.g., line **621** is always 50 feet in length as measured between the connecting point **620** and the UAV **640**). However, it may be useful for each UAV **640**, **660** to be able to further articulate the marionette **610** by flying to differing positions as shown by arrows **641**, **661** but also concurrently (or when at a hover location in the flight plan) acting to change the length or selectively articulate one or more of the tethers or connecting lines.

[0083] For example, the UAVs **640**, **660** are shown to include winch assemblies **646** and **666** to reel in and reel out the connecting lines in a concurrent or independent manner to articulate the marionette while hovering or while flying to a new location. Particularly, the winch assembly **646** includes

winches/reels **647**, **648**, **649** attached to lines **631**, **621**, **625**, respectively, and operable concurrently or independently by the UAVs local controls or via a GCS to reel in or out **650** the lines (e.g., shorten (increase tension) or lengthen (decrease tension). Similarly, the winch assembly **666** includes winches/reels **667**, **668**, **669** attached to lines **623**, **629**, **633**, respectively, and operable to concurrently or independently (by the local UAV controller or the fleet management module of the GCS) to reel in or out **670** the lines (shorten or lengthen the lines or increase or reduce tension in the lines). As will be appreciated, the display system **600** provides effective articulation of the marionette as the UAVs **640**, **660** can also be used to move and support the marionette **610** within an aerial display space above a group of spectators.

[0084] The inventors recognized that since the UAVs were being controlled in a flocked manner to support two or more marionettes that the marionettes along with their supporting UAVs can be used to create a marionette assembly or super marionette or flying structure made up of a number of structure components or portions. One may be reminded of childhood toys in which building blocks or other pieces can be combined and put together in numerous ways to create a different finished product or toy. The same can be achieved with flying or hovering aerial marionettes supported and articulated by a flock of UAVs.

[0085] For example, in a show spectacular or aerial display environment, there is a desire to extend 3D aerial displays, such as "floats", to multiple structures that self-assemble into a superstructure. The final assembly or product may be floating in the air or have lower portions contacting or even partially supported by the ground or terrestrial supports. The use of flying UAVs or robots (such as multicopters) that can be controlled by both ground station logic and onboard autonomous logic is used in an aerial display system to create a flying structure or marionette assembly.

[0086] The superstructure or marionette assembly may be assembled and disassembled as part of the aerial display show by choosing the marionettes (UAV payloads) as well as defining the flight plan with way points that cause the payloads to "assemble" or at least hover in spaces/locations that appear to form a superstructure to the spectators (new 3D display or visual effect by combining the marionettes/UAV payloads). In other words, each marionette or payload of each UAV of the display system may be thought of as a component or portion of a larger assembly or superstructure when the UAVs move to "assembled" positions or way points of their respective flight plans.

[0087] FIG. **7** illustrates one example of an aerial display system **700** being configured and operated to provide a display or show involving the assembly (or disassembly) of a superstructure or marionette assembly **720** over a viewing area or the ground **705**. As shown, a number of marionettes/structure payloads supported by one or more UAVs (e.g., multicopters) have been combined on or over the ground **705** to form an aerial superstructure **720**.

[0088] Further, as the UAVs perform their flight plans, the superstructure **720** is expanded or completed with the addition of more structure payloads/marionettes. Particularly, a first, second and third marionette assemblies/structure components **730**, **740**, **750** are shown to be hovering nearby the assembly/superstructure **720**. The marionette assemblies **730**, **740**, **750** include a structure payload or marionette **734**, **744**, **754** each supported by one or more UAVs **732**, **742**, **752**.

[0089] These UAVs **732**, **742**, **752** are operated to follow a flight plan (or control by the GCS, not shown) to move the payloads **734**, **744**, **754** as shown with arrows **735**, **745**, **755** toward (or away from) the others payloads/marionettes of the superstructure/assembly **720** to further assemble (or disassemble) the superstructure/assembly **720**. Each marionette/payload is designed to match nearby payloads and even, in some cases, to "engage" the nearby components to provide an appearance of being assembled to or joined to the neighboring payloads/marionettes to form the superstructure. The fabricated/assembled superstructure **720** may simply hover in place or its parts may be articulated by movement of the UAVs while remaining "assembled". In other cases, the entire assembly/superstructure **720** may move over the ground **705** to new locations.

[0090] Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

[0091] The aerial display systems described provide a number of useful advantages over prior display techniques and devices. For example, large characters can be flown safely to make a dramatic display. The characters Or marionettes can be articulated much more freely and effectively than, for example, a dirigible. The marionette's body may be formed of very light materials yet can be made to appear to be relatively hard or firm (e.g., hard-appearing edges and features) while remaining soft and flexible, which improves safety for an audience of spectators below the flying marionette. The use of a lightweight marionette allows a team or number of relatively small UAVs to provide the relatively small suspension force required to keep the marionette afloat with or without articulation. The marionettes described are not tethered to the ground or are not ground based but, instead, are supported by flying vehicles that provides a unique and dynamic aerial show.

We claim:

1. A system for providing an aerial display, comprising:

a plurality of unmanned aerial vehicles (UAVs); and

a ground control system with a processor executing a fleet manager module and with memory storing a different flight plan for each of the UAVs; and

a marionette with a body and articulatable appendages attached to the body, wherein the body and appendages are supported with tether lines extending between the marionette and the UAVs,

wherein, during a display time period, the UAVs concurrently execute the flight plans to position and articulate the marionette within a display air space.

2. The system of claim **1**, wherein the UAVs each comprises a multicopter.

3. The system of claim **2**, wherein each of the multicopters comprises a local controller operating to move the multicopter through a series of way points defined by the flight plan associated with the multicopter.

4. The system of claim **1**, wherein, the marionette comprises a plurality of connecting elements each attached to an end of one of the tether lines.

5. The system of claim **4**, wherein each of the UAVs is attached via one of the tether lines to only one of the connecting elements.

6. The system of claim 4, wherein each of the UAVs is attached via the tether lines to two or more of the connecting elements.

7. The system Of claim 6, wherein each of the UAVs includes a winch assembly for selectively adjusting a length of each of the tether lines to articulate the marionette during the display time period.

8. The system of claim 4, wherein at least some of the connecting elements is coupled to an articulating frame on or within the body or the appendages of the marionette.

9. The system of claim 1, further including a second marionette supported by one or more of the UAVs, wherein the flight plans define flight paths causing the marionettes to be positioned in proximity in the display air space to form a floating superstructure.

10. A flight control method, comprising:

at a plurality of multicopters, receiving a flight plan unique to each of the multicopters;

concurrently operating the multicopters to execute the flight plans within an air space; and

during the operating of the multicopters, supporting a string puppet with the multicopters, whereby the string puppet is supported and articulated in the air space by movement of the multicopters.

11. The method of claim 10, further including:

providing a communications channel between pairs of the multicopters;

with a first one of the multicopters detecting a second one of the multicopters in a predefined space proximal to the first one of the multicopters; and

operating the display payload of the first one of the multicopters in a new manner based on an identity of the second one of the multicopters.

12. The method of claim 10, wherein the string puppet comprises a plurality of connecting elements each attached to an end of a tether line extending to one of the multicopters.

13. The method of claim 12, wherein each of the multicopters is attached via the tether lines to two or more of the connecting elements and wherein the method includes selectively adjusting a length of each of the tether lines to articulate the string puppet during the operating of the multicopters step.

14. The method of claim 10, further comprising supporting a second string puppet with the multicopters and wherein the operating of the multicopters includes moving the string puppets into adjacent positions to form a floating superstructure movable and articulatabie in the air space.

15. An apparatus for use in an aerial display, comprising:

a marionette with a plurality of connecting elements;

a plurality of UAVs; and

tethering lines extending between the UAVs and the connecting elements, wherein the UAVs have synchronized movement through a display air space to support and articulate the marionette to move between at least a first position and a second position.

16. The apparatus of claim 15, wherein the UAVs each include local controllers executing flight plans to move each of the UAVs along a predefined flight path to provide the articulation and positioning of the marionette.

17. The apparatus of claim 15, wherein the connecting elements are provided on joints or frames of the marionette.

18. The apparatus of claim 15, wherein each of the UAVs is attached to at least two of the tethering lines.

19. The apparatus of claim 18, wherein the UAVs include a mechanism for selectively and independently articulating the at least two of the tethering lines.

20. The apparatus of claim 15, wherein the marionette comprises a plurality of subcomponents each including one or more of the connecting elements and wherein the subcomponents may be assembled and disassembled in the display air space by movement of the UAVs along predefined flight paths.

* * * * *