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Priest et al.

(10) **Patent No.: US 10,231,133 B2**
(45) **Date of Patent: *Mar. 12, 2019**

(54) **3D MODELING OF CELL SITES AND CELL TOWERS WITH UNMANNED AERIAL VEHICLES**

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

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/160,890**

(22) Filed: **May 20, 2016**

(65) **Prior Publication Data**

US 2017/0142596 A1 May 18, 2017

Related U.S. Application Data

(63) Continuation-in-part of application No. 14/736,925, filed on Jun. 11, 2015, now Pat. No. 9,669,945, and

(Continued)

(51) **Int. Cl.**

B64D 47/08 (2006.01)
G01C 21/00 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04W 16/18*** (2013.01); ***B64C 39/022*** (2013.01); ***B64C 39/024*** (2013.01); ***B64D 47/08*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC B64C 2201/027; B64C 2201/127; G01S 13/89; G08G 5/02; G08G 5/025; G05D 1/0676

(Continued)

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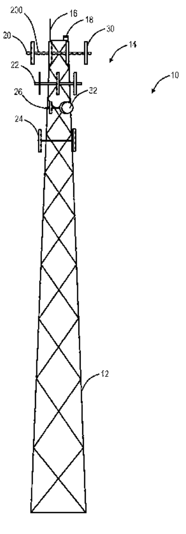
Primary Examiner — Kimberly A Williams

(74) *Attorney, Agent, or Firm* — Clements Bernard Walker PLLC; Lawrence A. Baratta, Jr.

(57) **ABSTRACT**

A method for modeling a cell site with an Unmanned Aerial Vehicle (UAV) includes causing the UAV to fly a given flight path about a cell tower at the cell site, wherein a launch location and launch orientation is defined for the UAV to take off and land at the cell site such that each flight at the cell site has the same launch location and launch orientation; obtaining a plurality of photographs of the cell site during about the flight plane, wherein each of the plurality of photographs is associated with one or more location identifiers; and, subsequent to the obtaining, processing the plurality of photographs to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs.

20 Claims, 26 Drawing Sheets



Related U.S. Application Data

a continuation-in-part of application No. 14/685,720, filed on Apr. 14, 2015, now Pat. No. 9,596,617, and a continuation-in-part of application No. 15/131,460, filed on Apr. 18, 2016, now Pat. No. 9,764,838.

(51) **Int. Cl.**

H04L 12/24	(2006.01)
B64C 39/02	(2006.01)
H04W 16/18	(2009.01)
G01S 19/33	(2010.01)
G05D 1/00	(2006.01)
G05D 1/08	(2006.01)

(52) **U.S. Cl.**

CPC ***G01C 21/00*** (2013.01); ***G01S 19/33*** (2013.01); ***G05D 1/0094*** (2013.01); ***G05D 1/0866*** (2013.01); ***H04L 41/22*** (2013.01); *B64C 2201/027* (2013.01); *B64C 2201/108* (2013.01); *B64C 2201/123* (2013.01); *B64C 2201/127* (2013.01); *B64C 2201/128* (2013.01); *B64C 2201/148* (2013.01)

(58) **Field of Classification Search**

USPC 345/427

See application file for complete search history.

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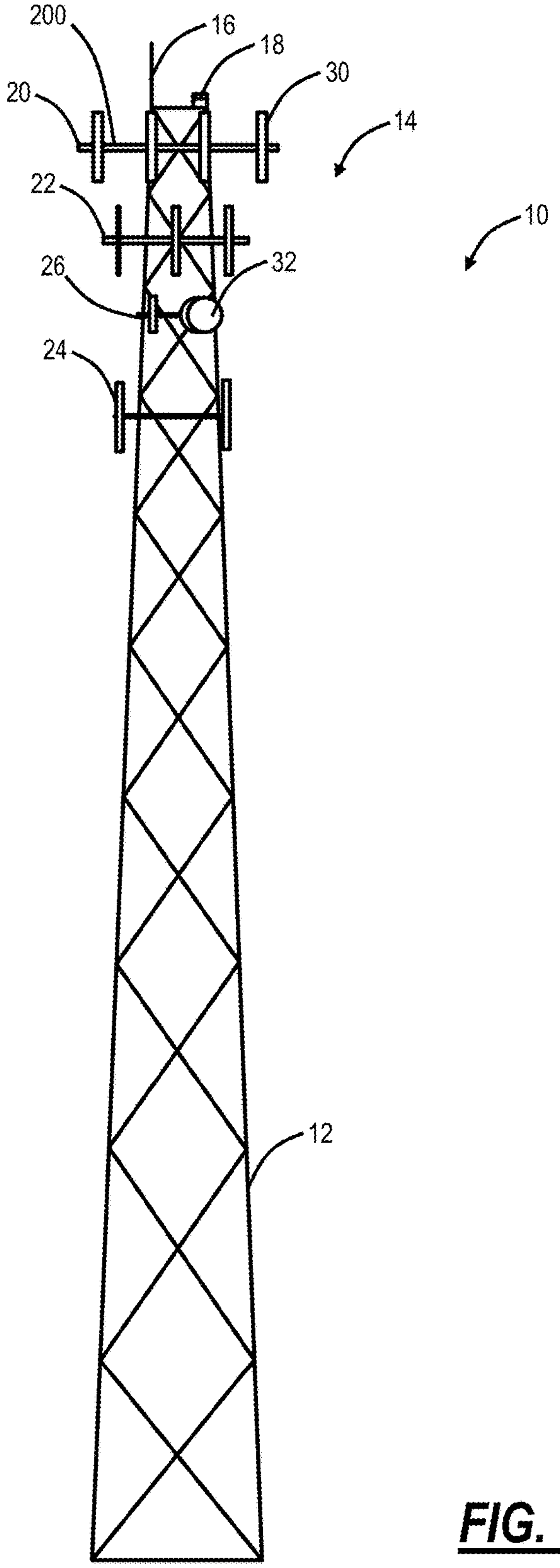


FIG. 1

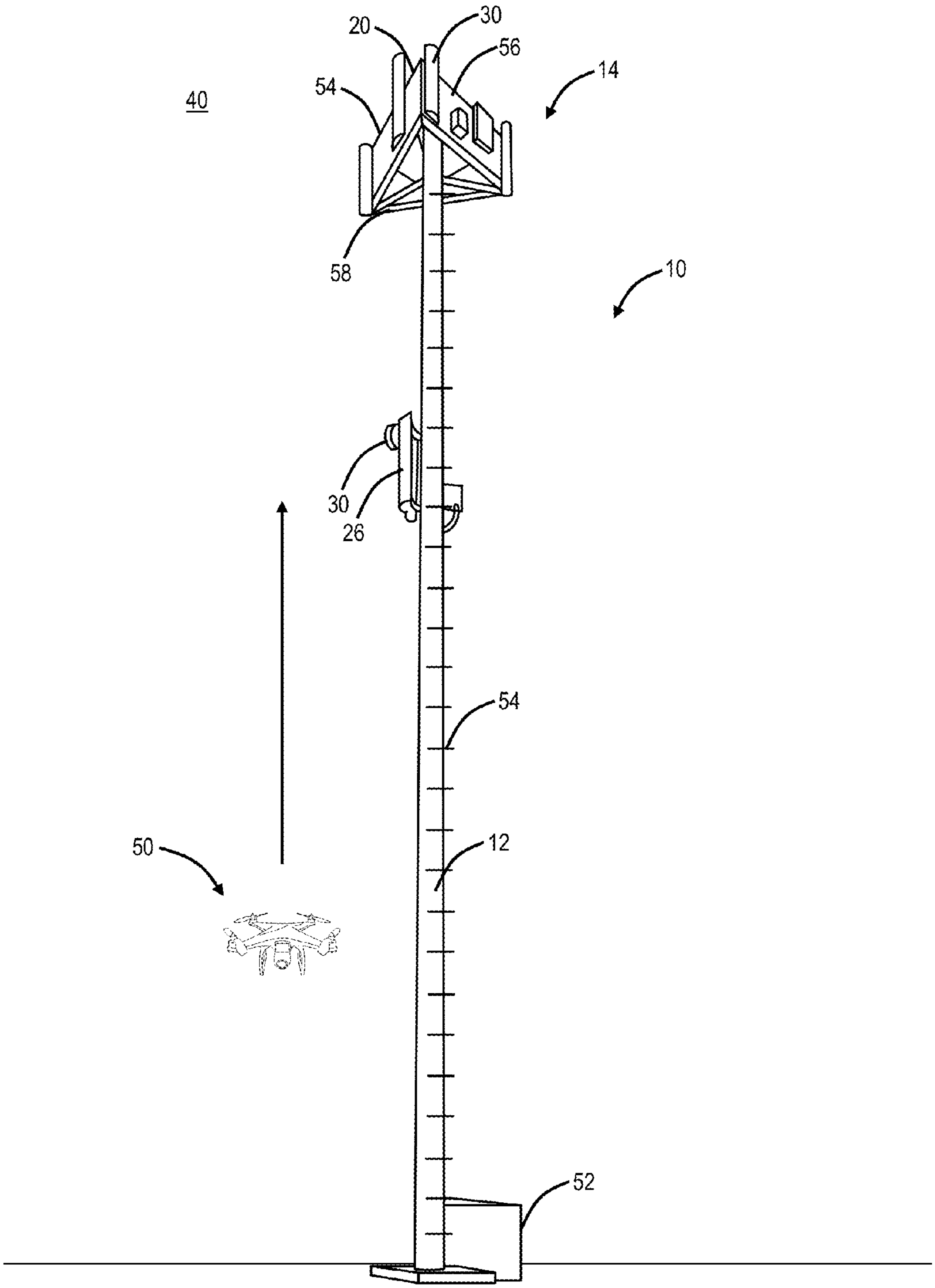


FIG. 2

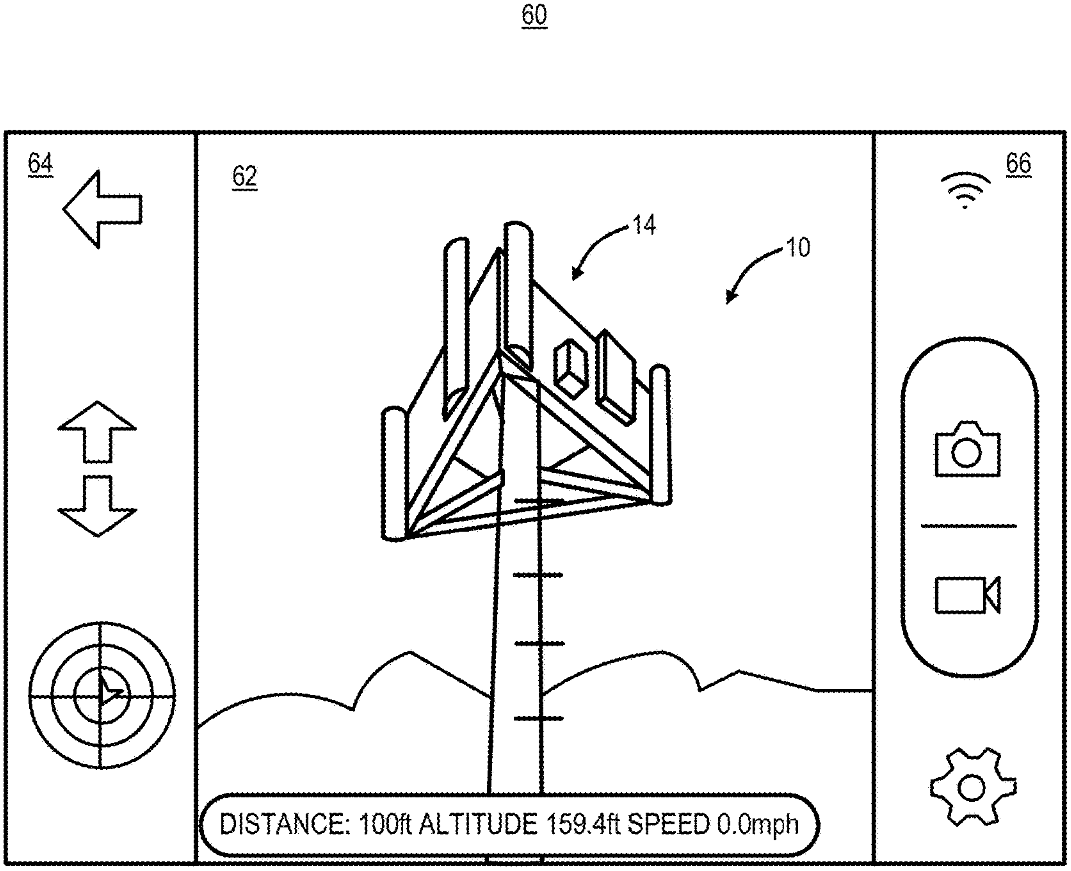


FIG. 3

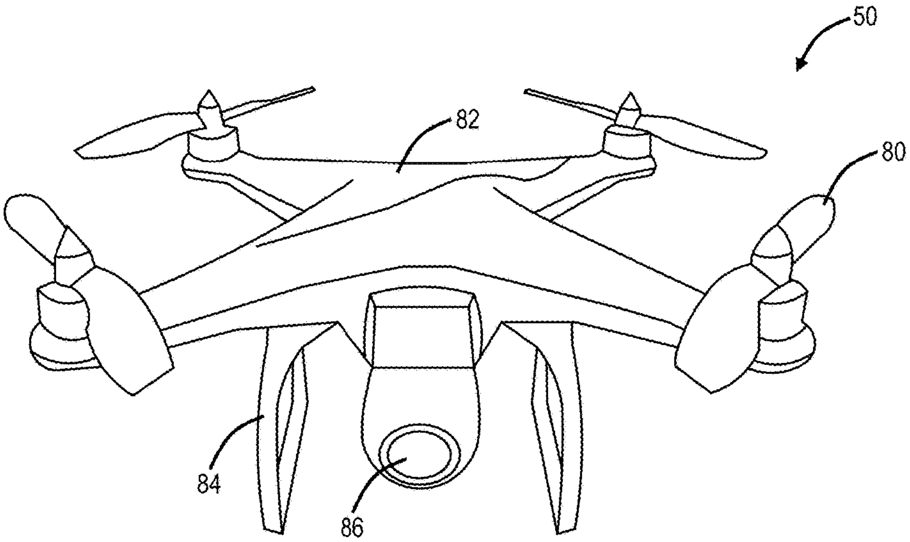

50
82
80
84
86

FIG. 4

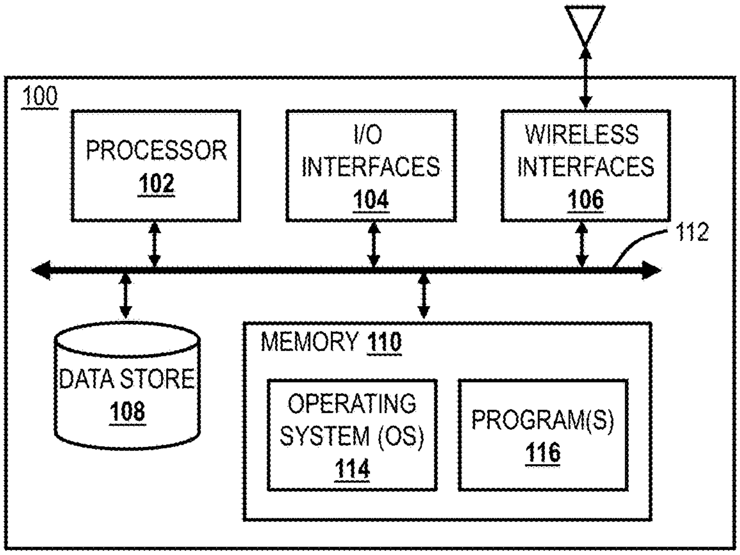

100
PROCESSOR 102
I/O INTERFACES 104
WIRELESS INTERFACES 106
112
DATA STORE 108
MEMORY 110
OPERATING SYSTEM (OS) 114
PROGRAM(S) 116

FIG. 5

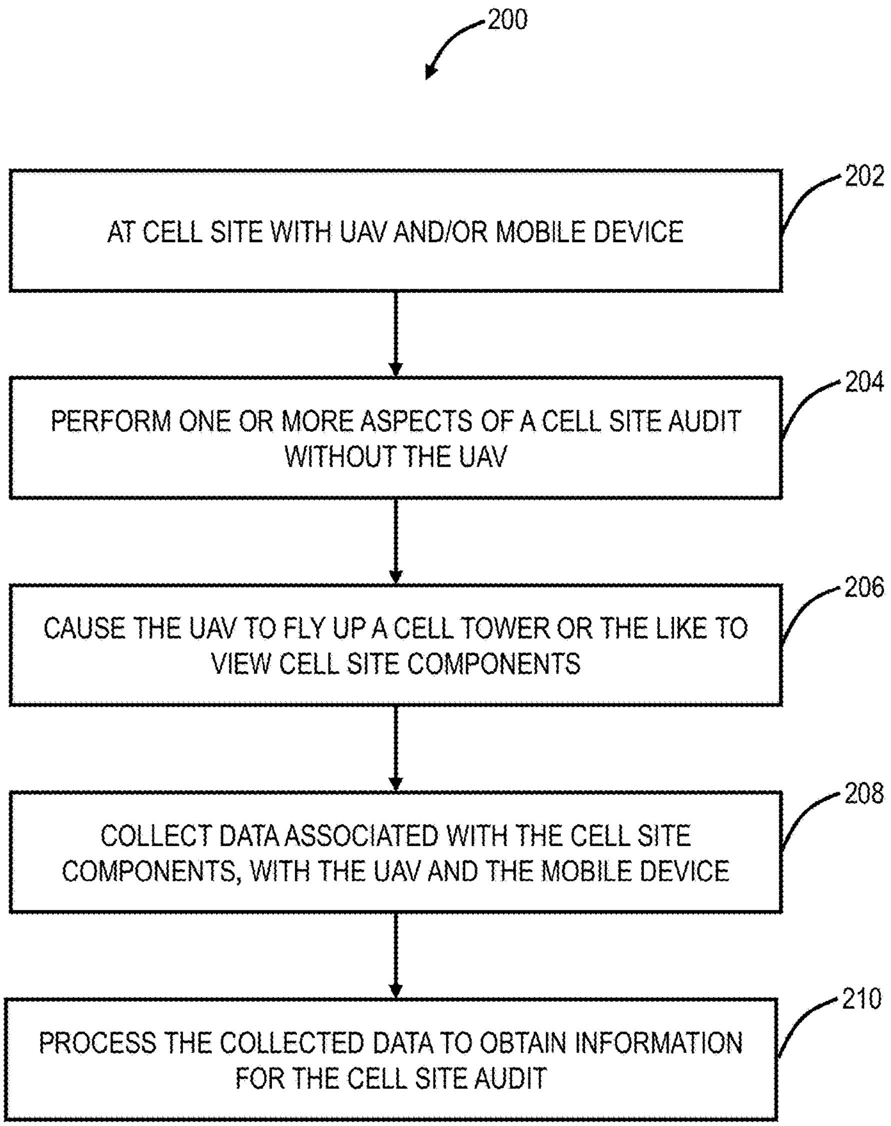

200
AT CELL SITE WITH UAV AND/OR MOBILE DEVICE
202
PERFORM ONE OR MORE ASPECTS OF A CELL SITE AUDIT WITHOUT THE UAV
204
CAUSE THE UAV TO FLY UP A CELL TOWER OR THE LIKE TO VIEW CELL SITE COMPONENTS
206
COLLECT DATA ASSOCIATED WITH THE CELL SITE COMPONENTS, WITH THE UAV AND THE MOBILE DEVICE
208
PROCESS THE COLLECTED DATA TO OBTAIN INFORMATION FOR THE CELL SITE AUDIT
210

FIG. 6

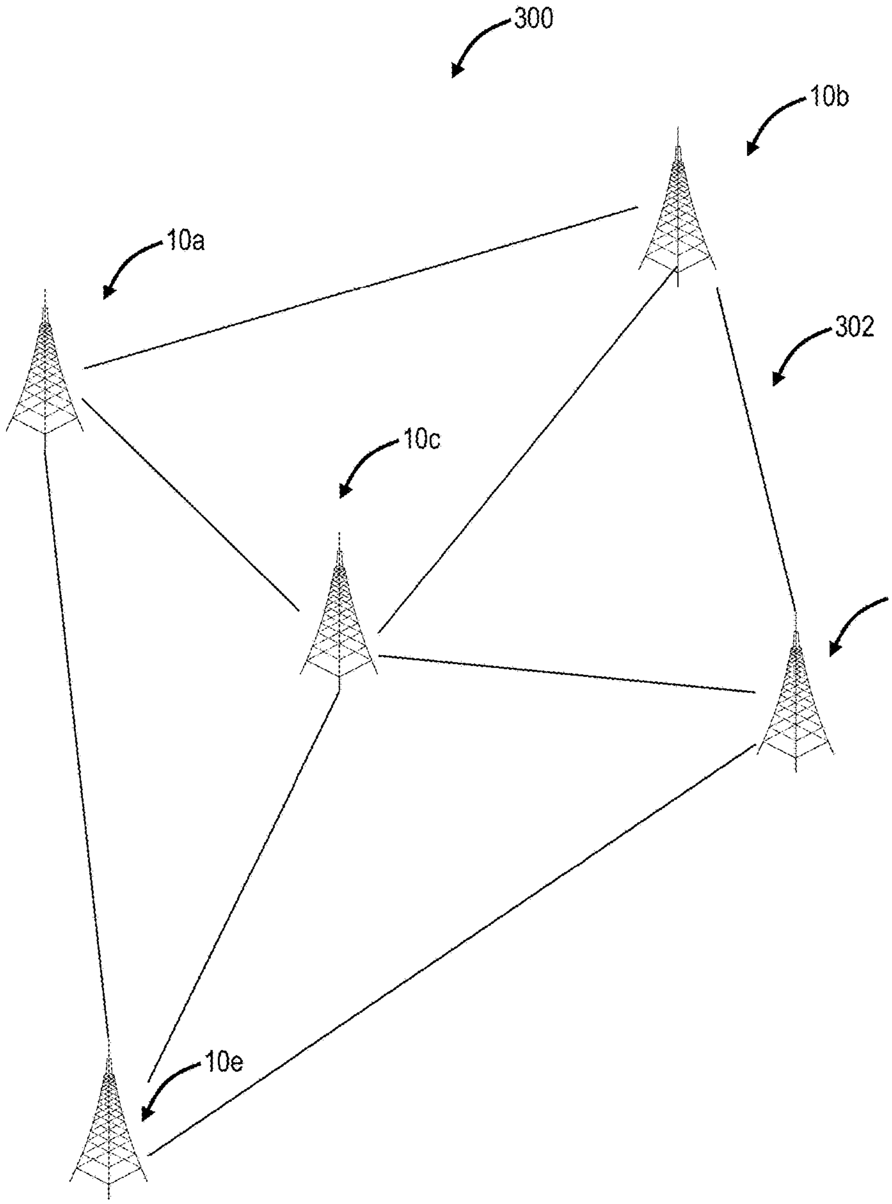


FIG. 7

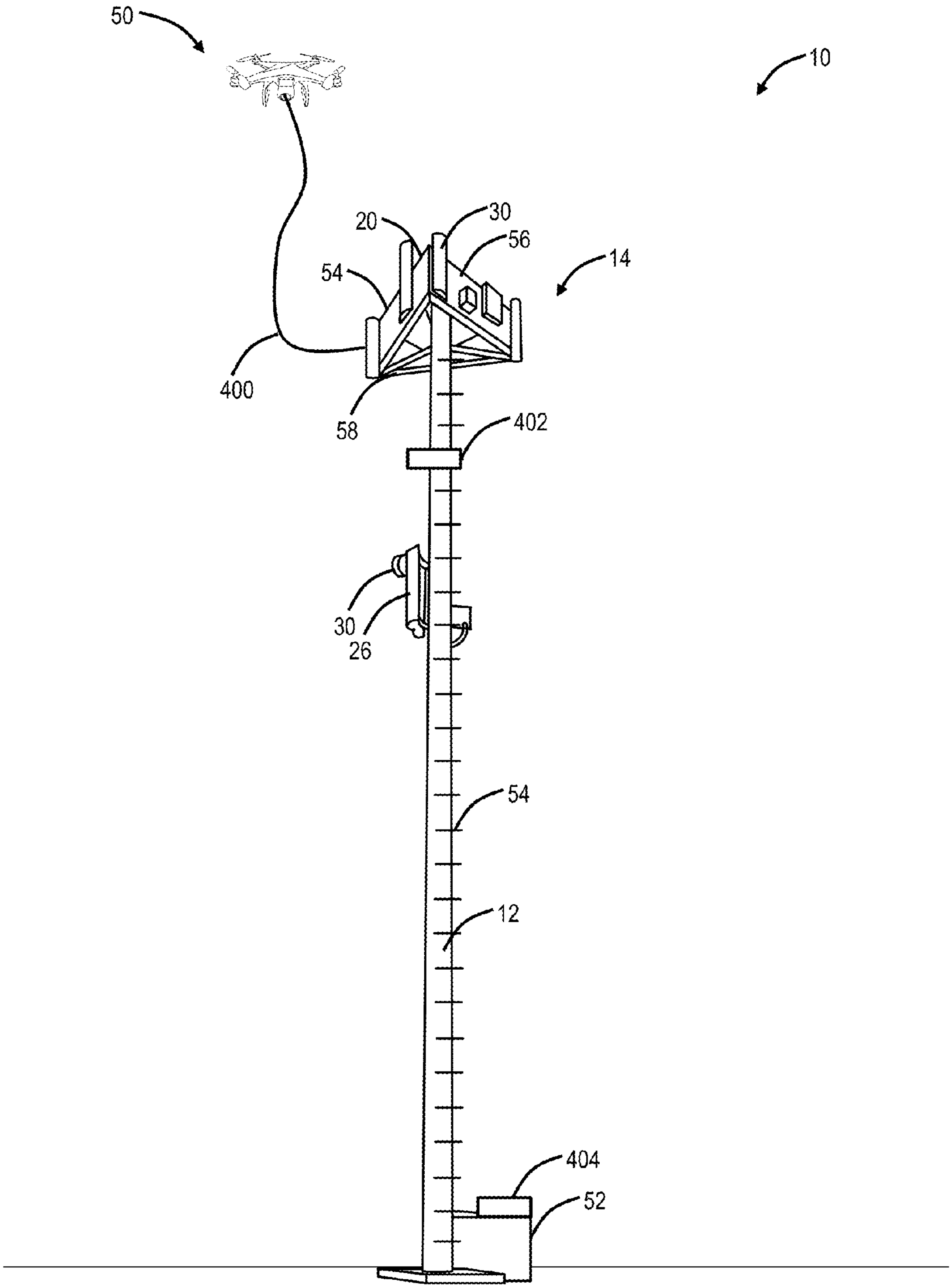


FIG. 8

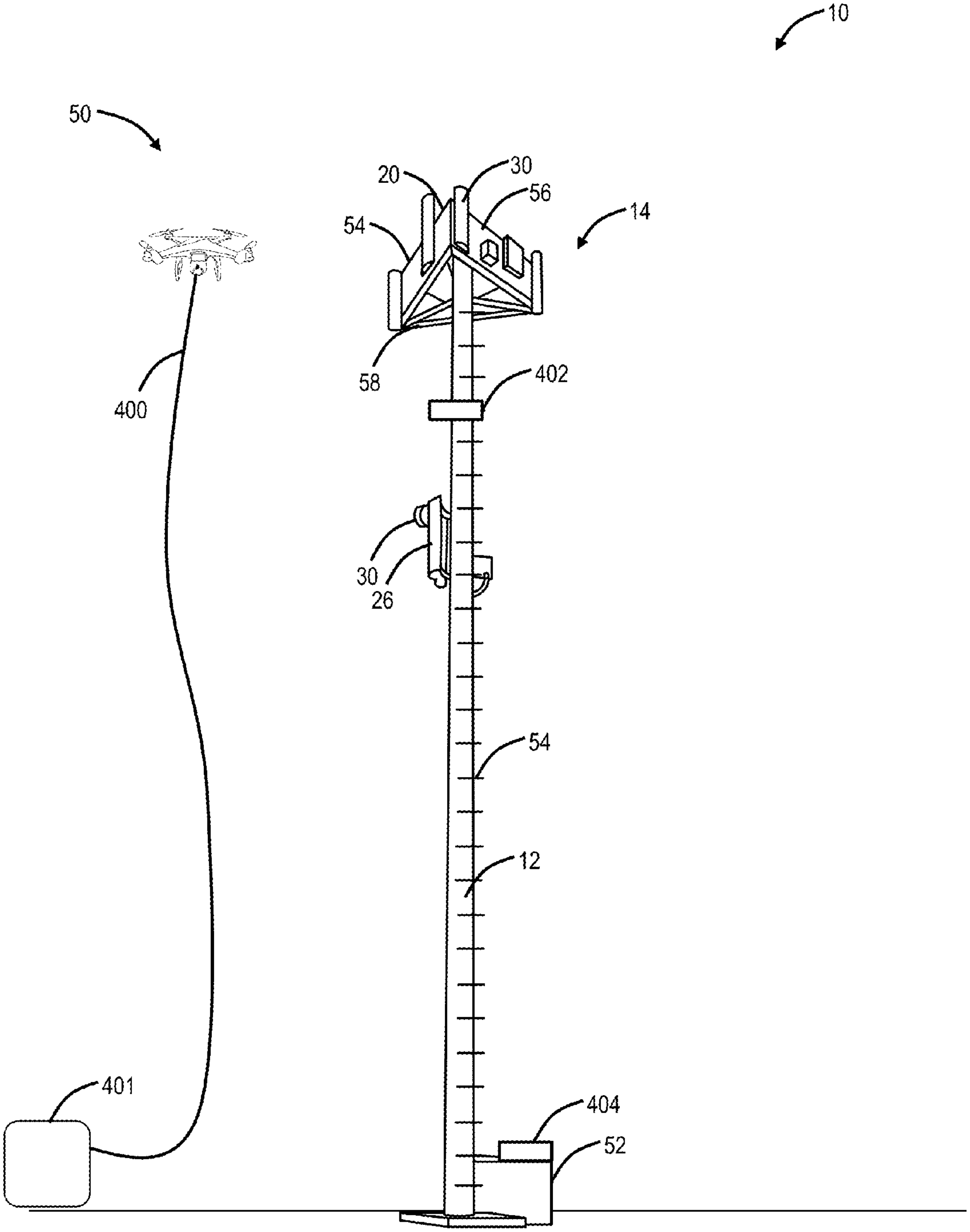


FIG. 9

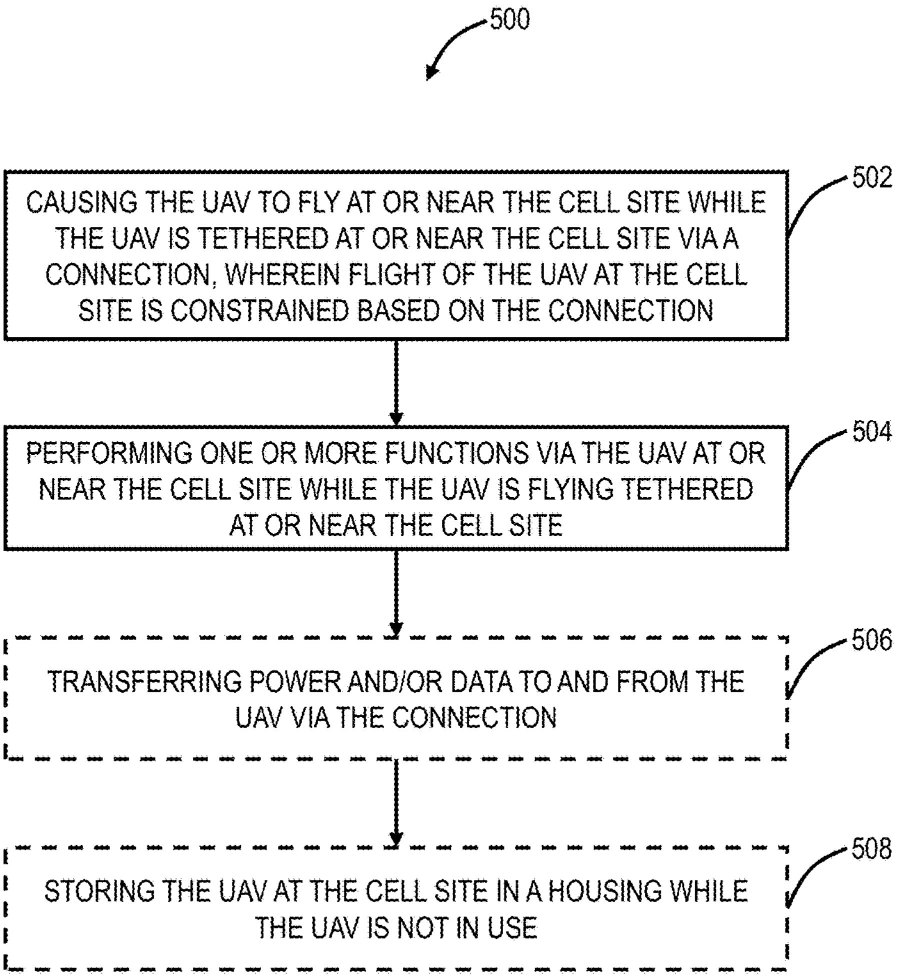

500
502
CAUSING THE UAV TO FLY AT OR NEAR THE CELL SITE WHILE THE UAV IS TETHERED AT OR NEAR THE CELL SITE VIA A CONNECTION, WHEREIN FLIGHT OF THE UAV AT THE CELL SITE IS CONSTRAINED BASED ON THE CONNECTION
504
PERFORMING ONE OR MORE FUNCTIONS VIA THE UAV AT OR NEAR THE CELL SITE WHILE THE UAV IS FLYING TETHERED AT OR NEAR THE CELL SITE
506
TRANSFERRING POWER AND/OR DATA TO AND FROM THE UAV VIA THE CONNECTION
508
STORING THE UAV AT THE CELL SITE IN A HOUSING WHILE THE UAV IS NOT IN USE

FIG. 10

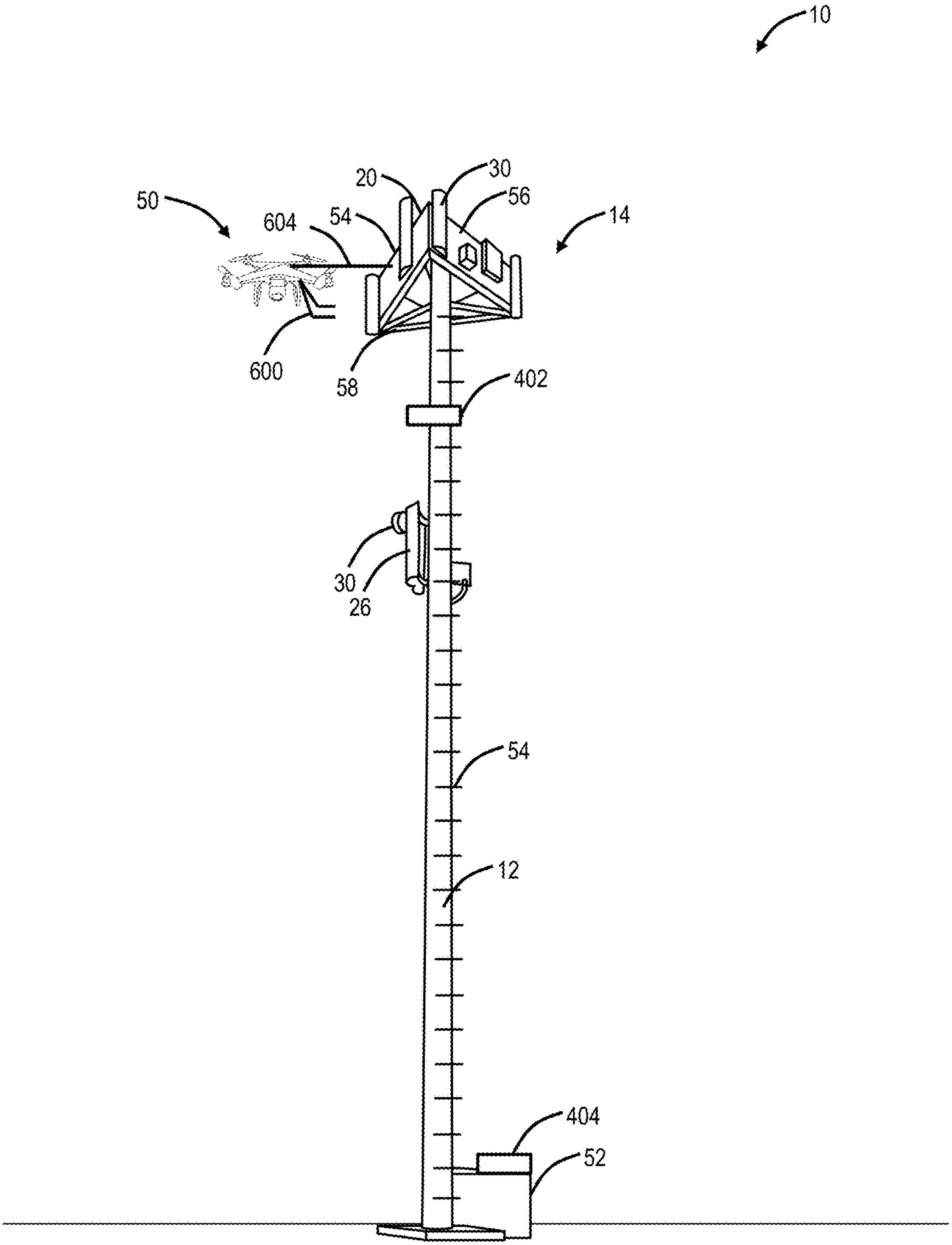


FIG. 11

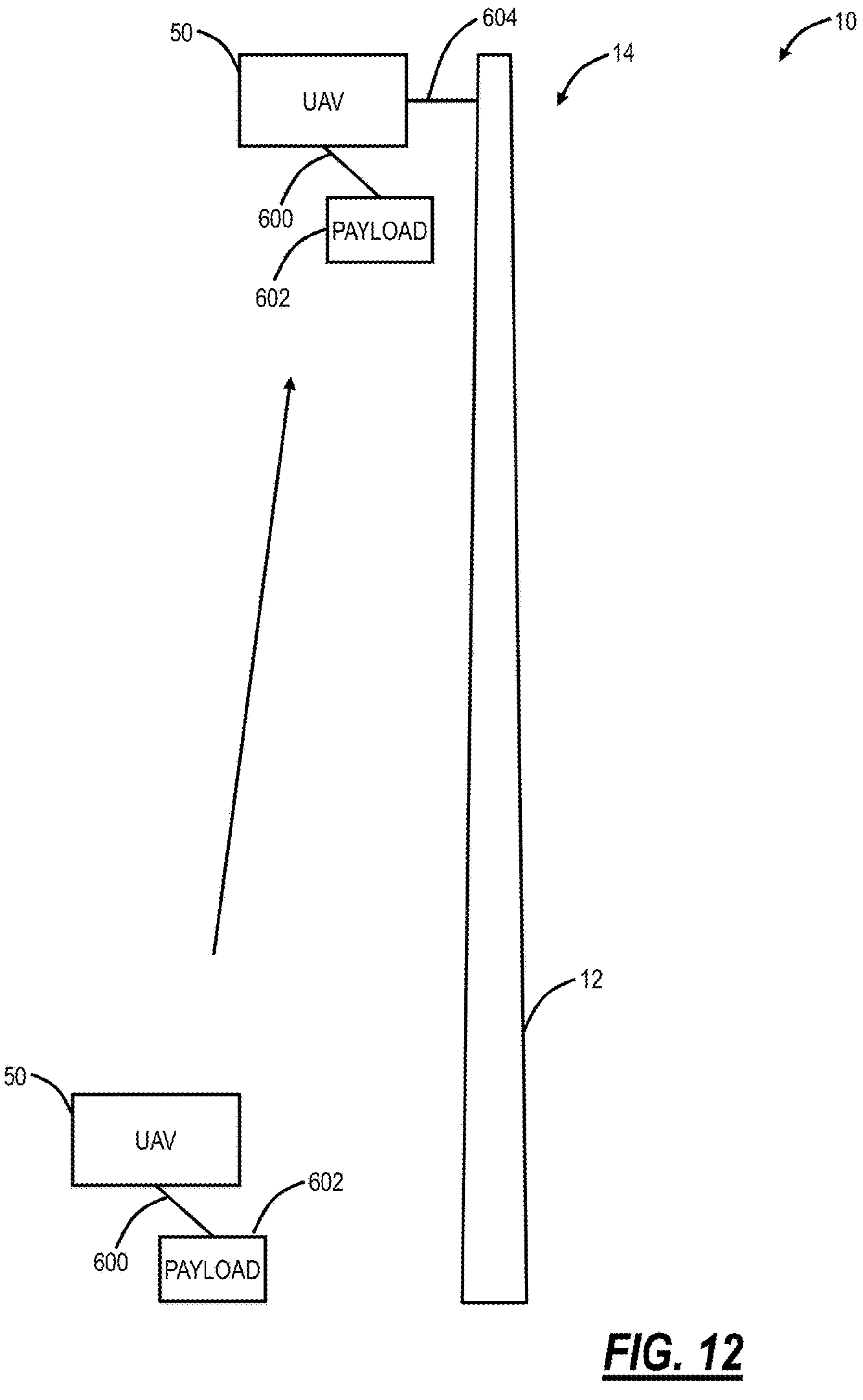


FIG. 12

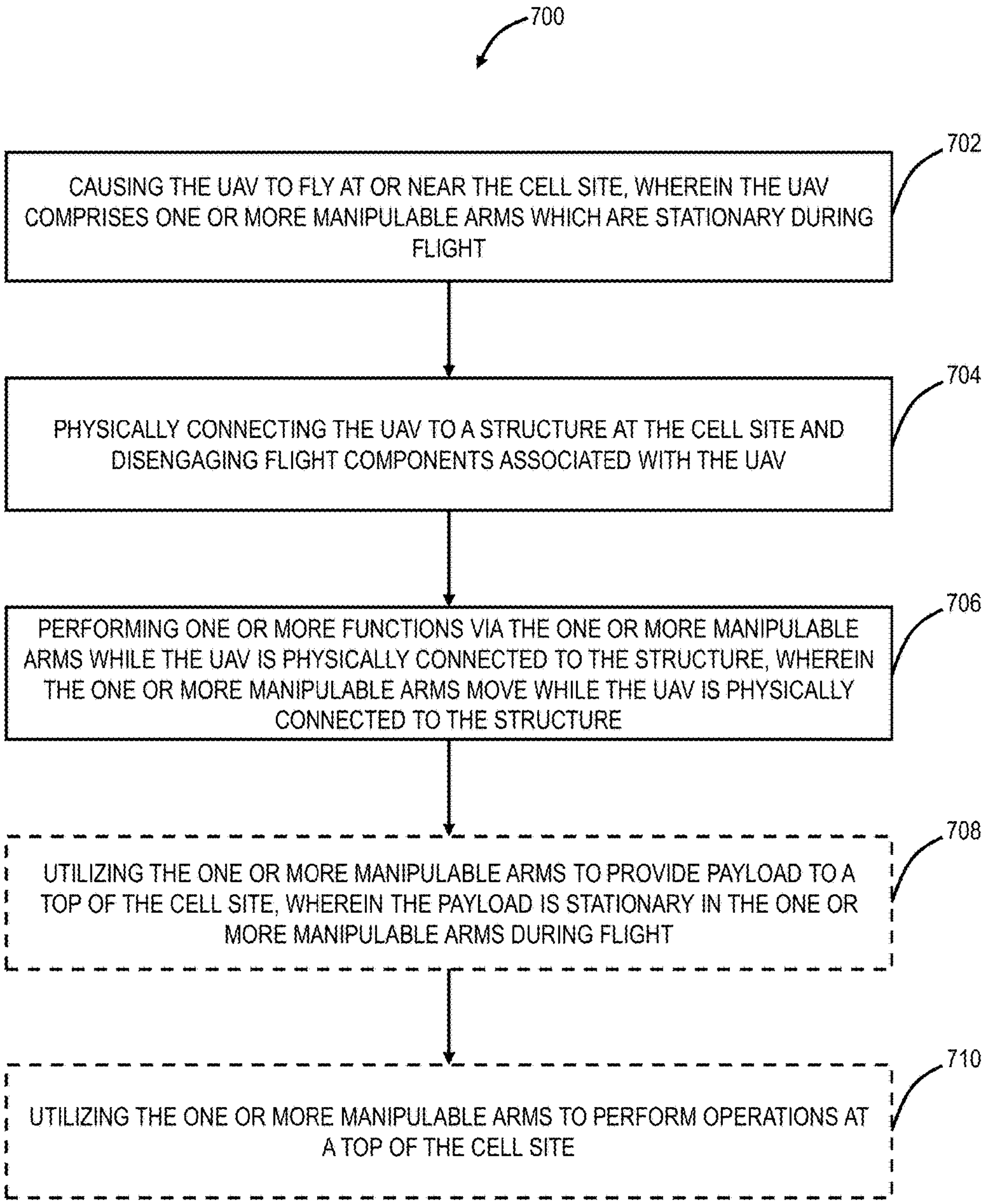

700
702
CAUSING THE UAV TO FLY AT OR NEAR THE CELL SITE, WHEREIN THE UAV COMPRISES ONE OR MORE MANIPULABLE ARMS WHICH ARE STATIONARY DURING FLIGHT
704
PHYSICALLY CONNECTING THE UAV TO A STRUCTURE AT THE CELL SITE AND DISENGAGING FLIGHT COMPONENTS ASSOCIATED WITH THE UAV
706
PERFORMING ONE OR MORE FUNCTIONS VIA THE ONE OR MORE MANIPULABLE ARMS WHILE THE UAV IS PHYSICALLY CONNECTED TO THE STRUCTURE, WHEREIN THE ONE OR MORE MANIPULABLE ARMS MOVE WHILE THE UAV IS PHYSICALLY CONNECTED TO THE STRUCTURE
708
UTILIZING THE ONE OR MORE MANIPULABLE ARMS TO PROVIDE PAYLOAD TO A TOP OF THE CELL SITE, WHEREIN THE PAYLOAD IS STATIONARY IN THE ONE OR MORE MANIPULABLE ARMS DURING FLIGHT
710
UTILIZING THE ONE OR MORE MANIPULABLE ARMS TO PERFORM OPERATIONS AT A TOP OF THE CELL SITE

FIG. 13

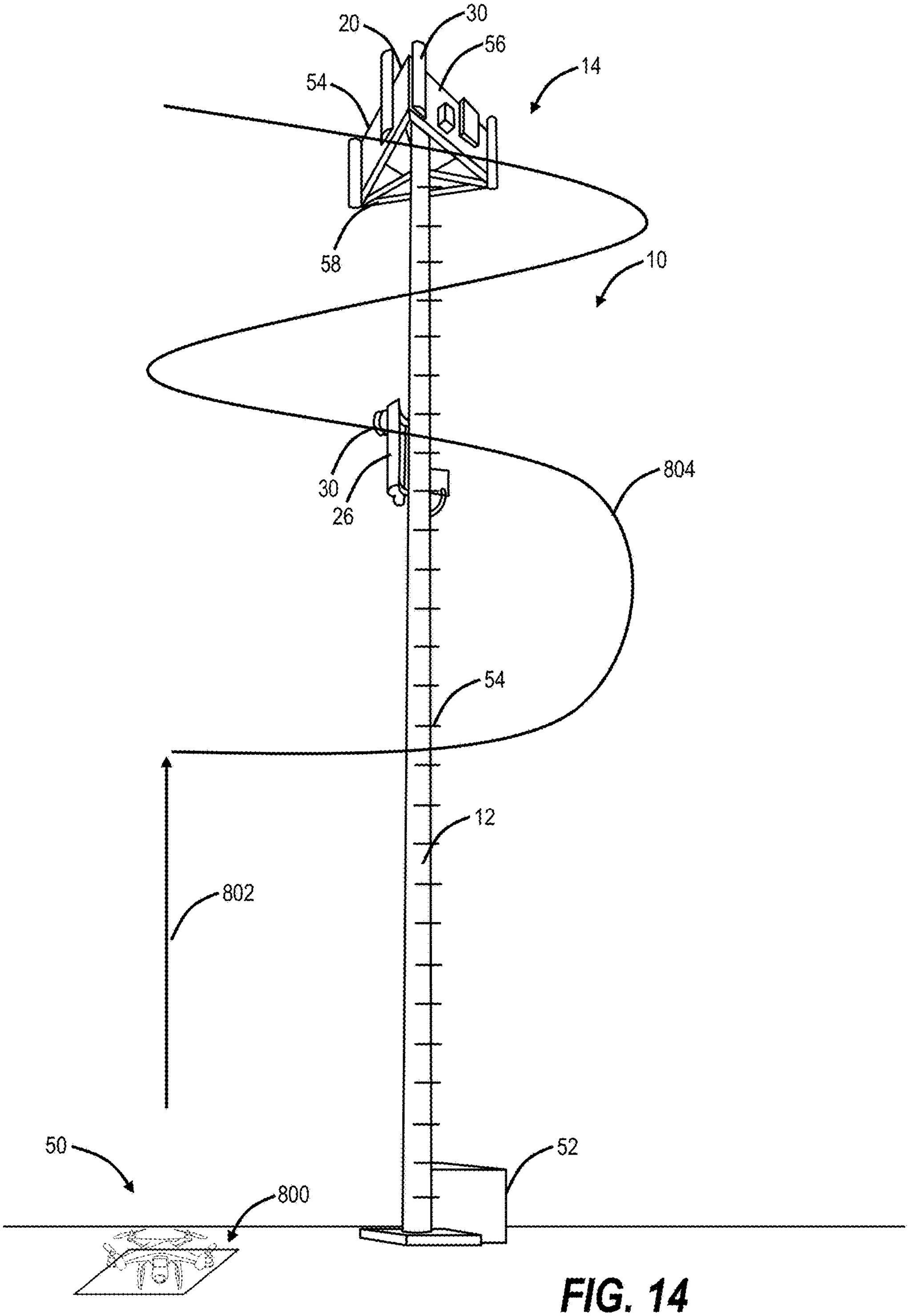


FIG. 14

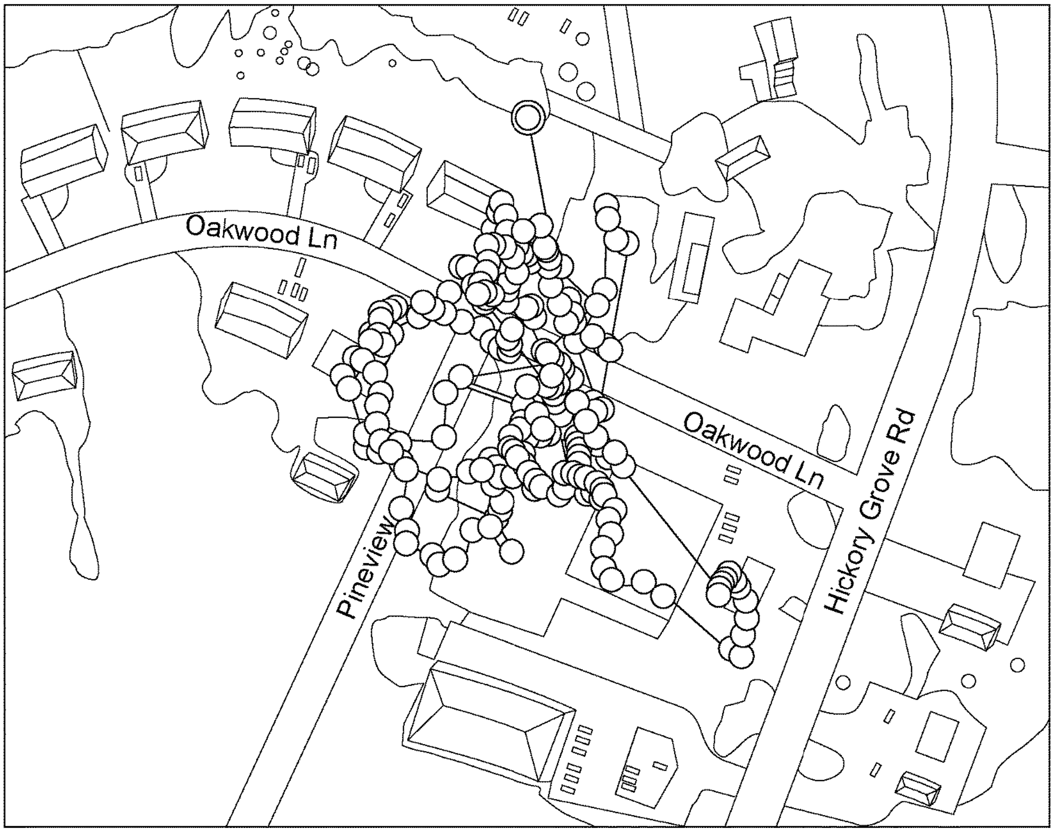


FIG. 15

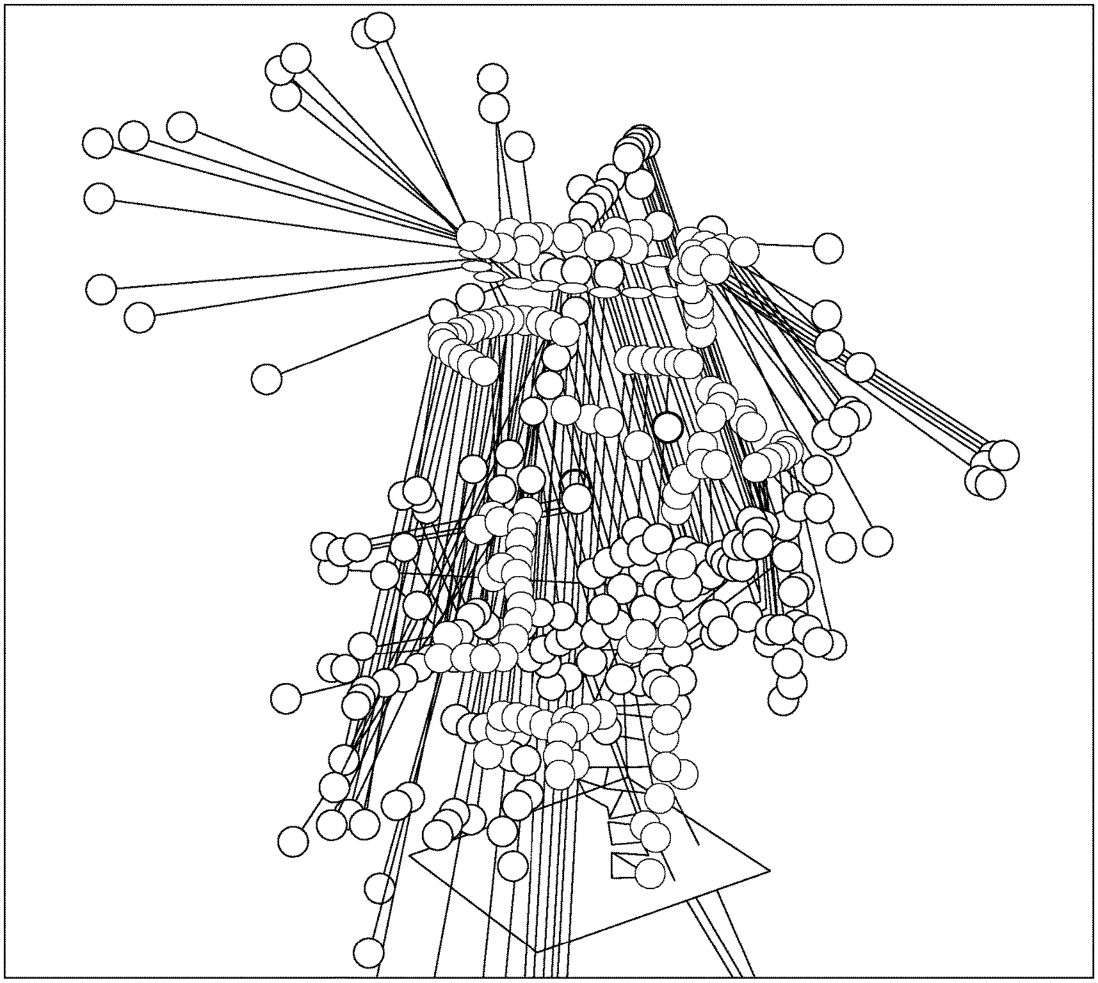


FIG. 16

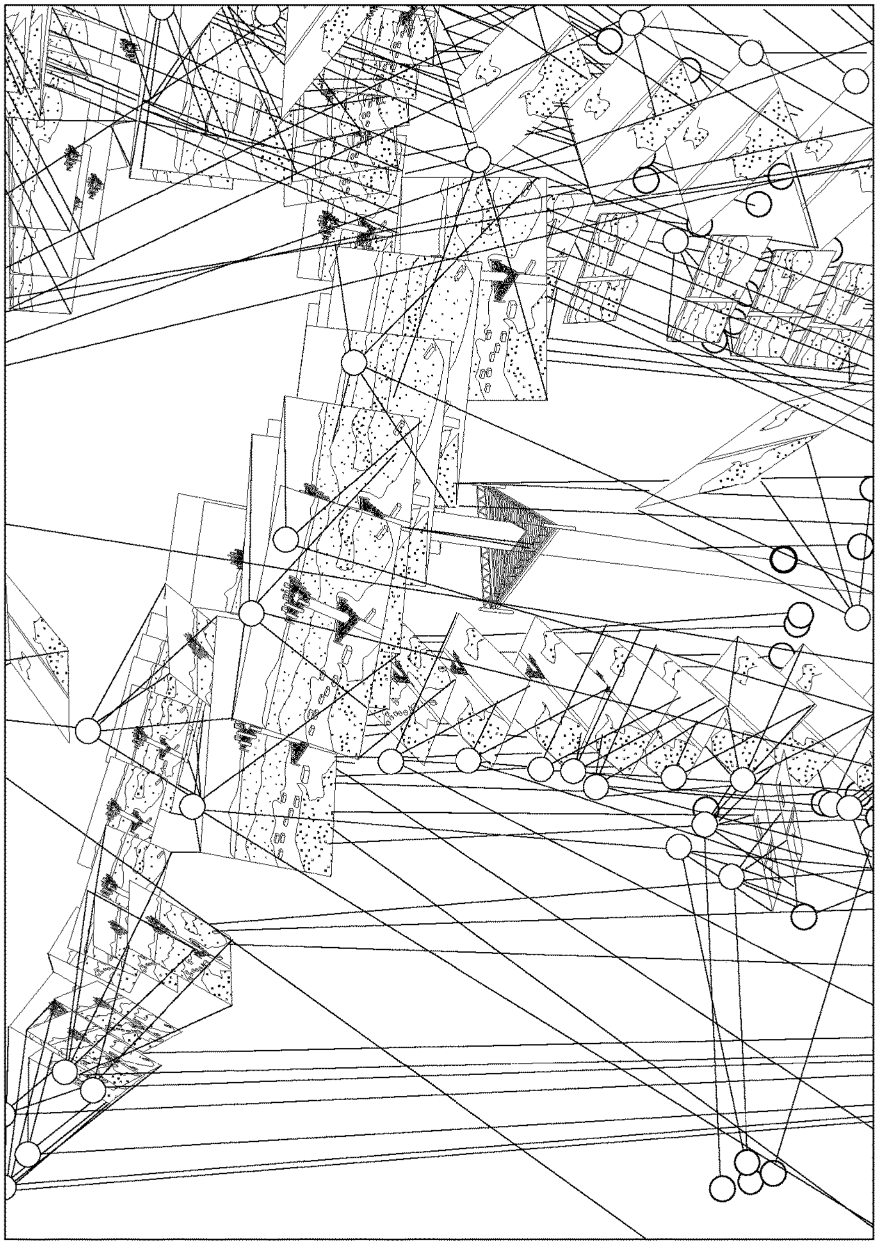
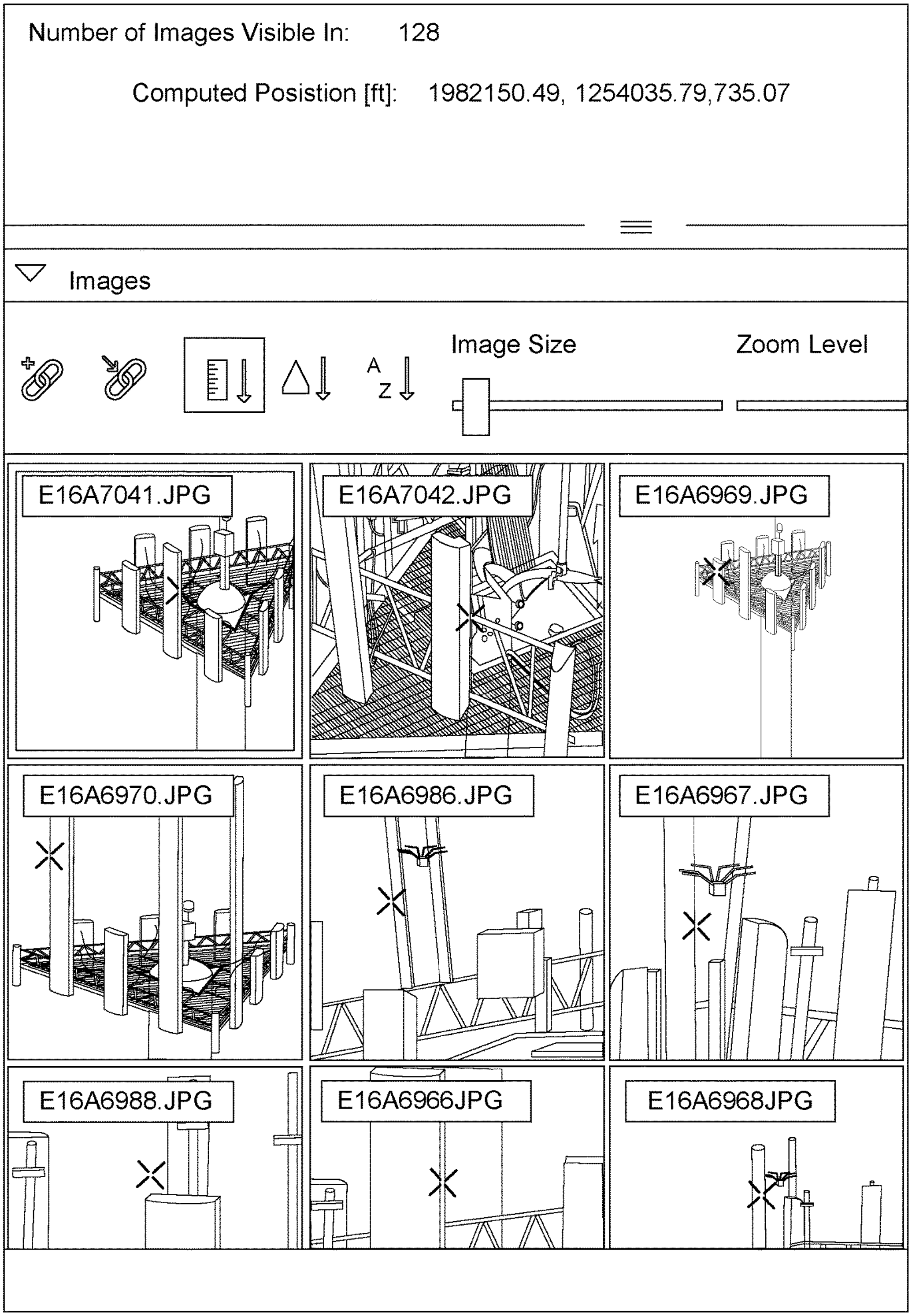


FIG. 17



Number of Images Visible In: 128

Computed Posistion [ft]: 1982150.49, 1254035.79,735.07

FIG. 18

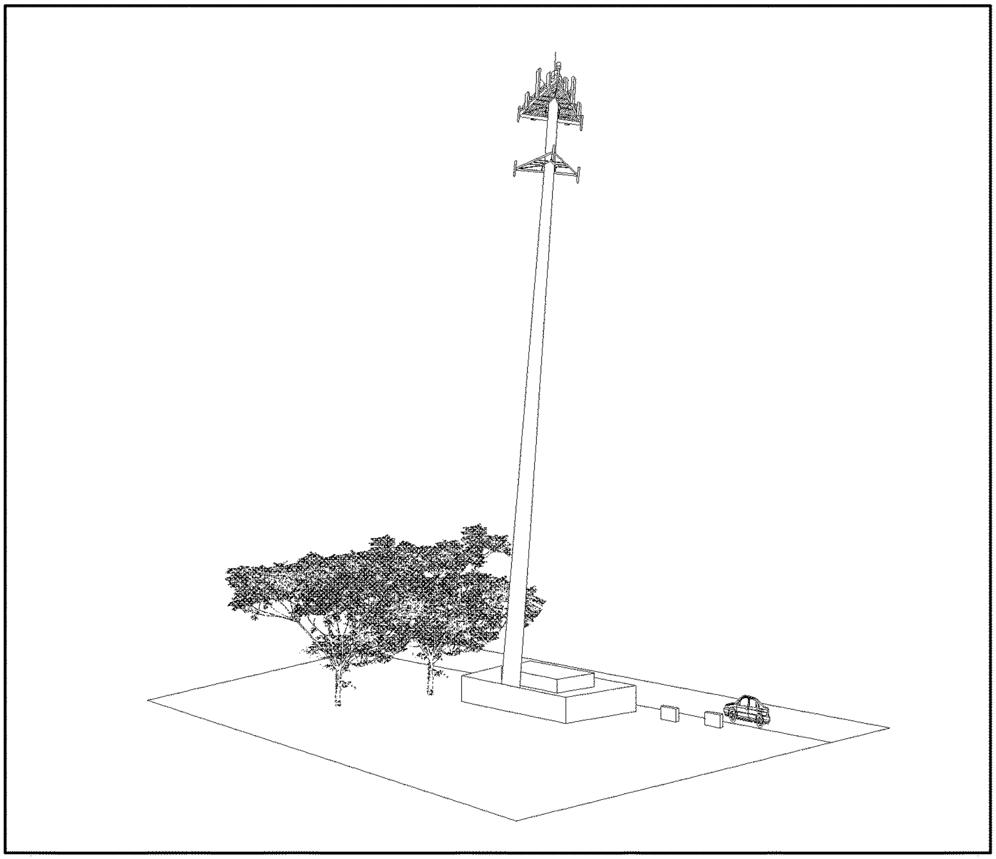
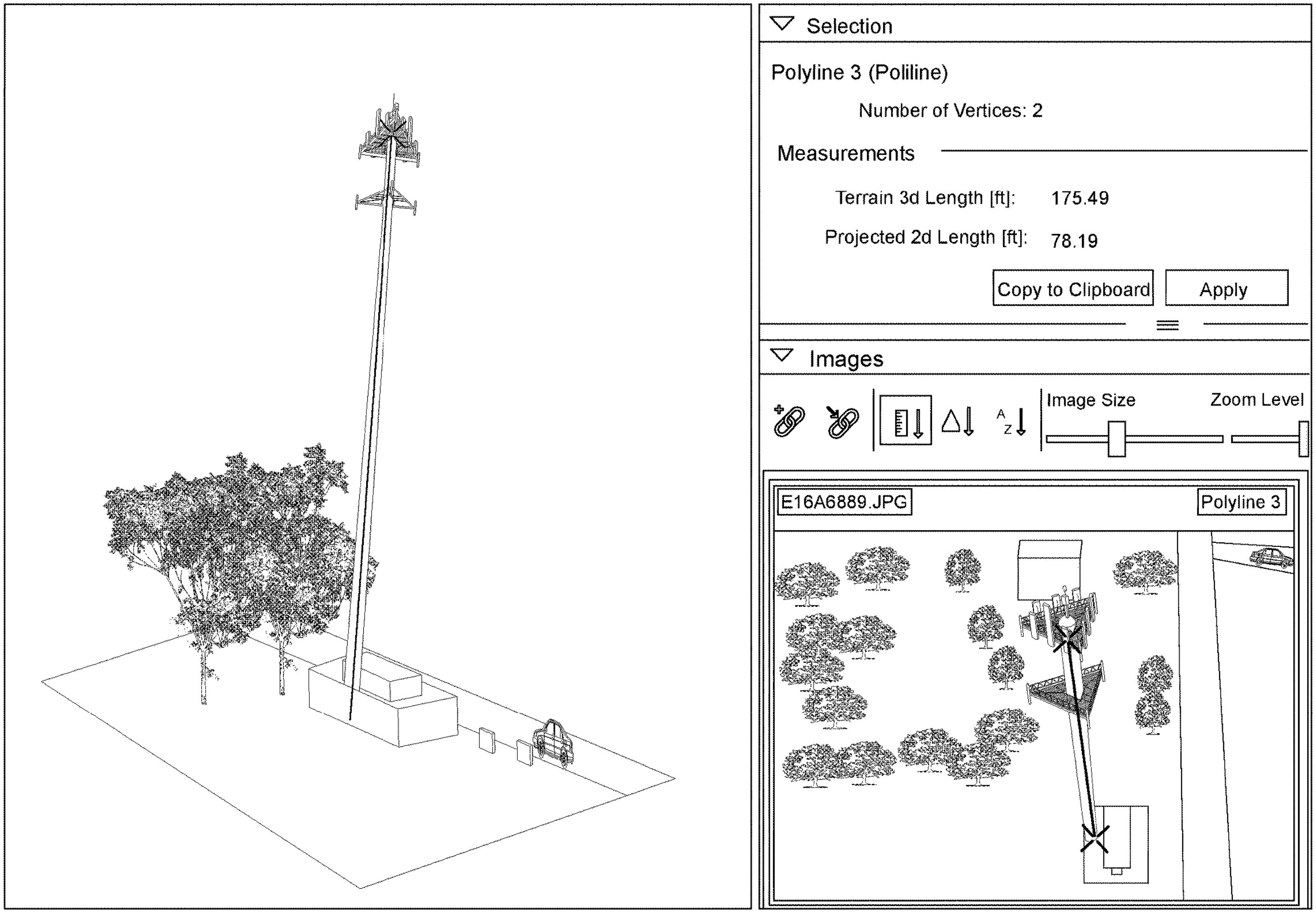


FIG. 19



Polyline 3 (Poliline)

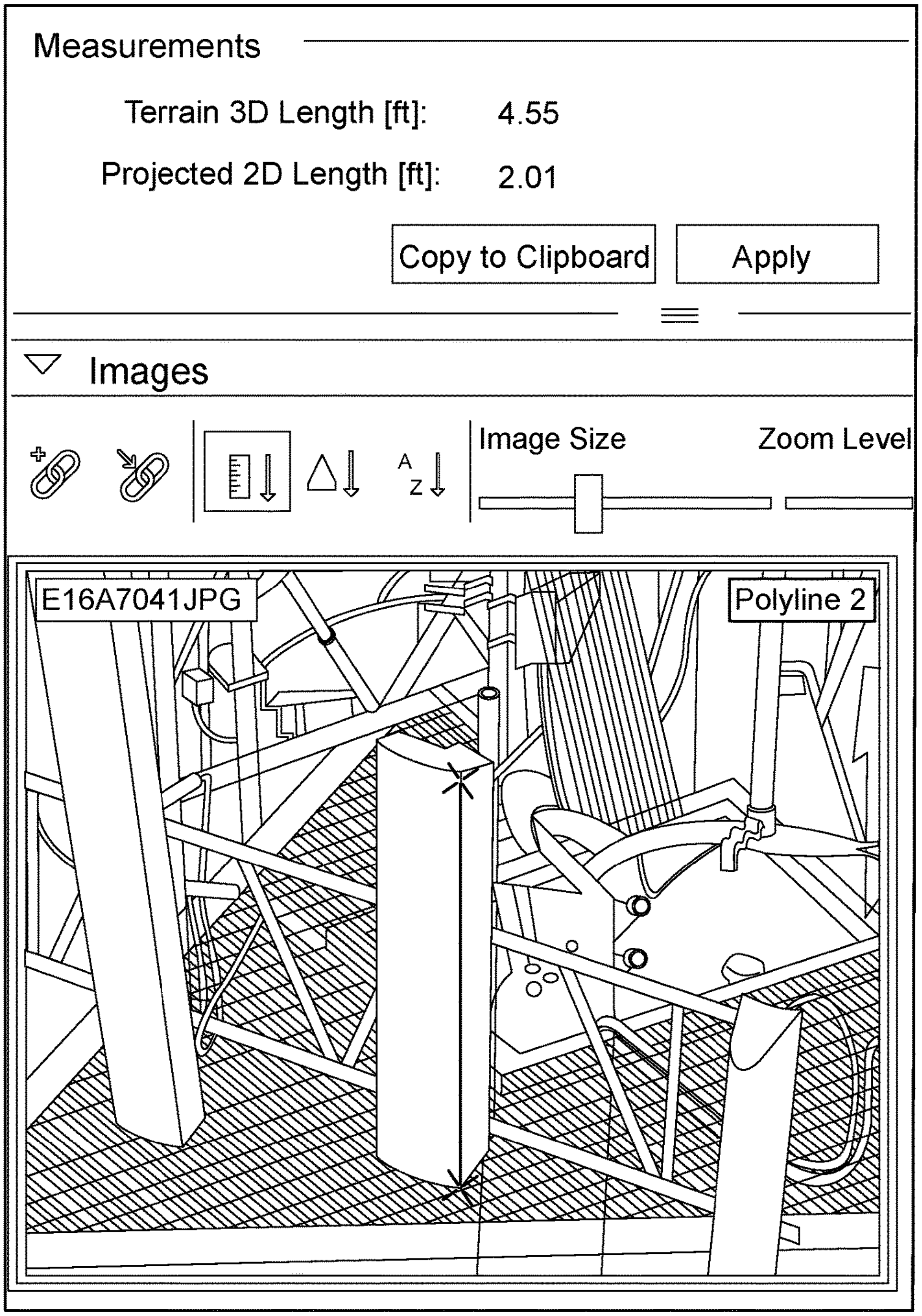
Number of Vertices: 2

Measurements

Terrain 3d Length [ft]: 175.49

Projected 2d Length [ft]: 78.19

FIG. 20



Measurements

Terrain 3D Length [ft]: 4.55

Projected 2D Length [ft]: 2.01

FIG. 21

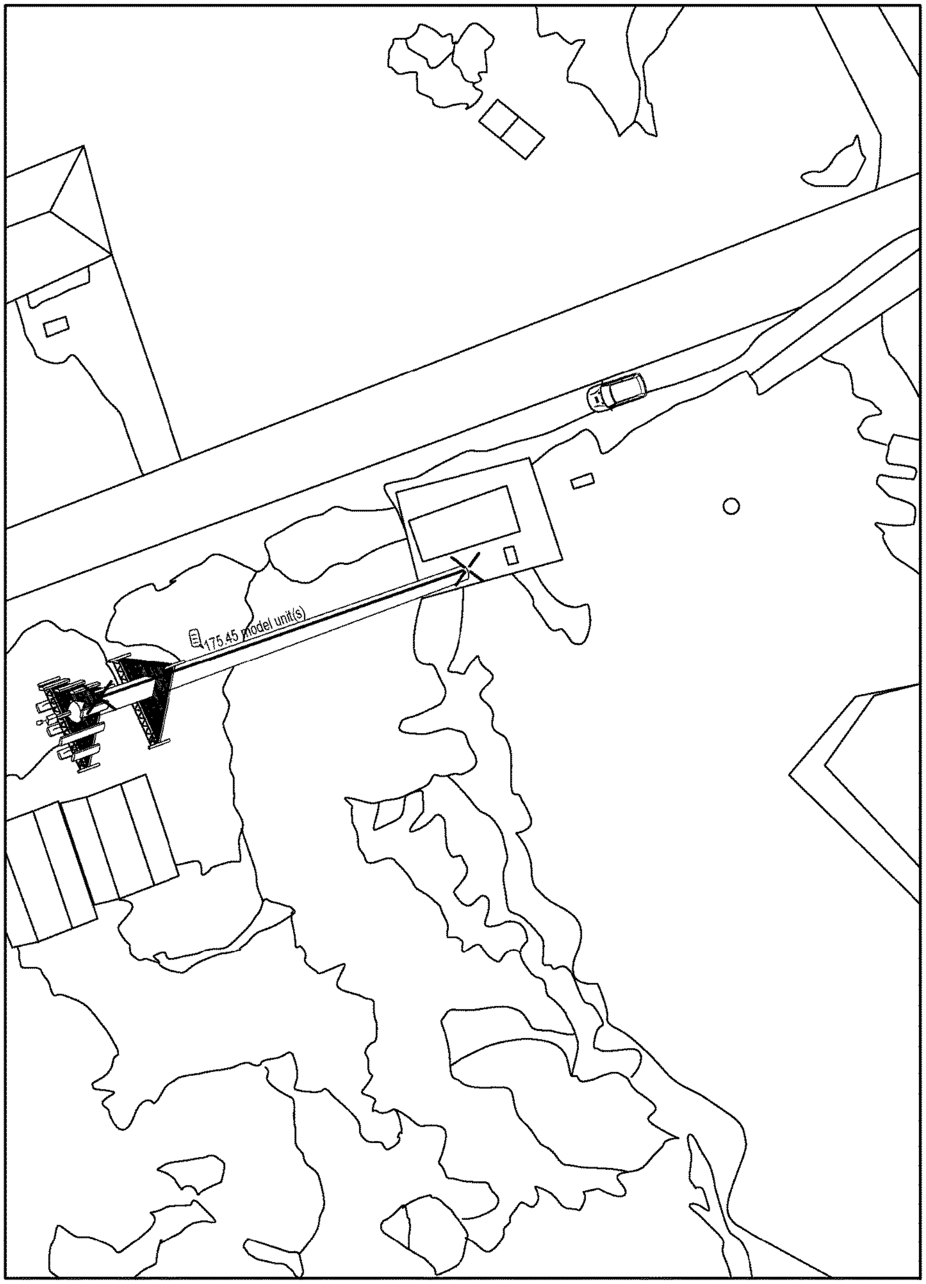


FIG. 22

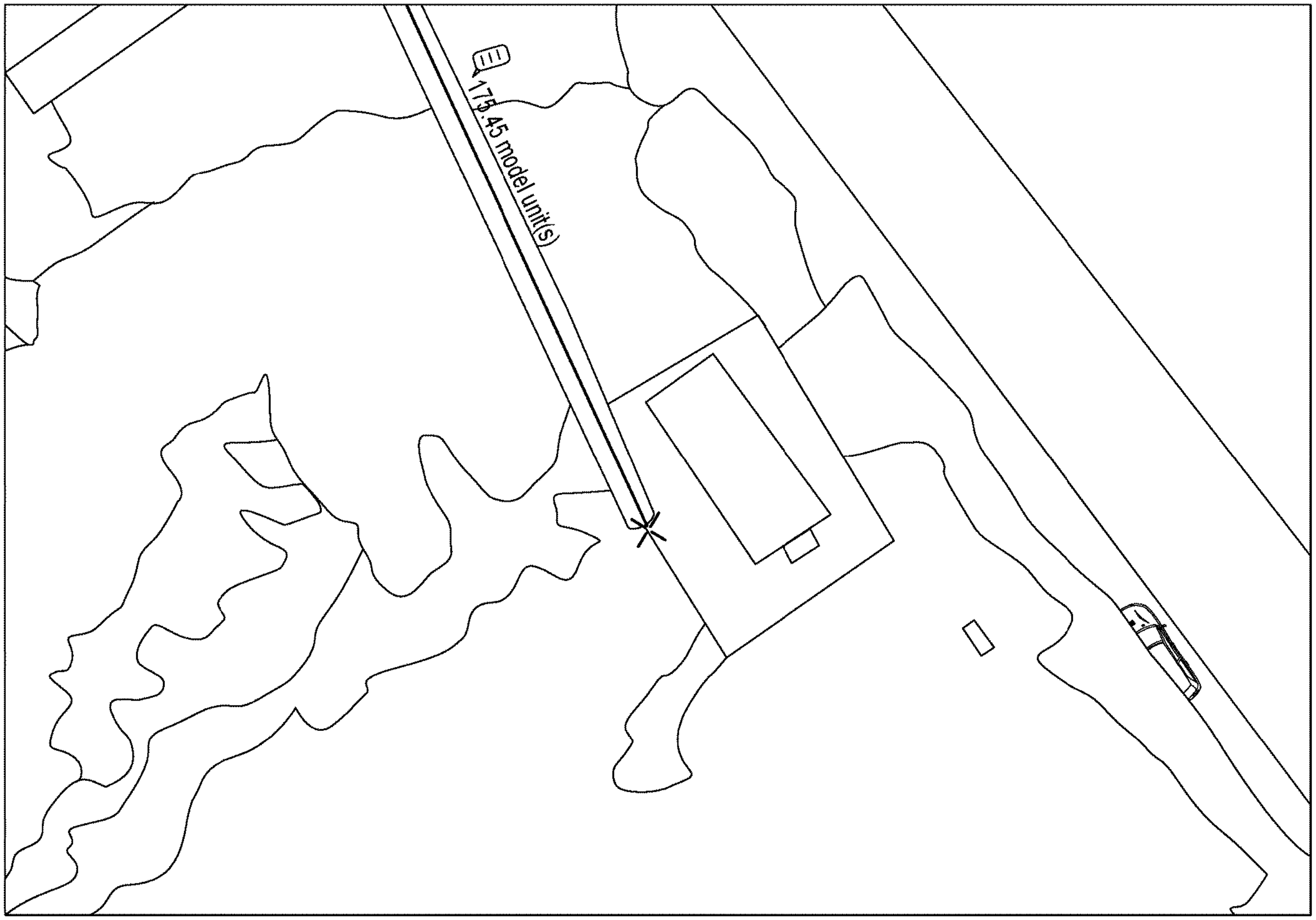
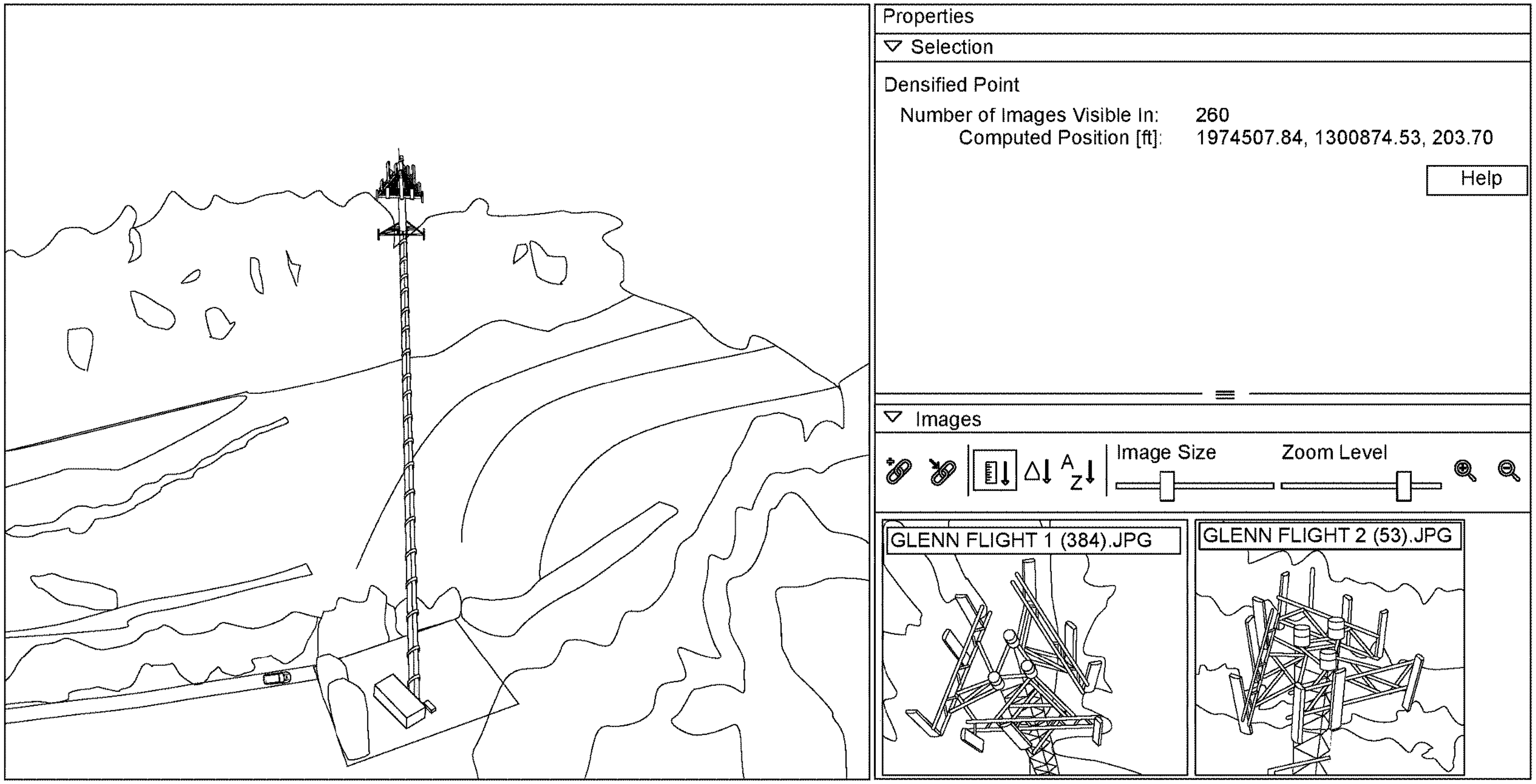


FIG. 23

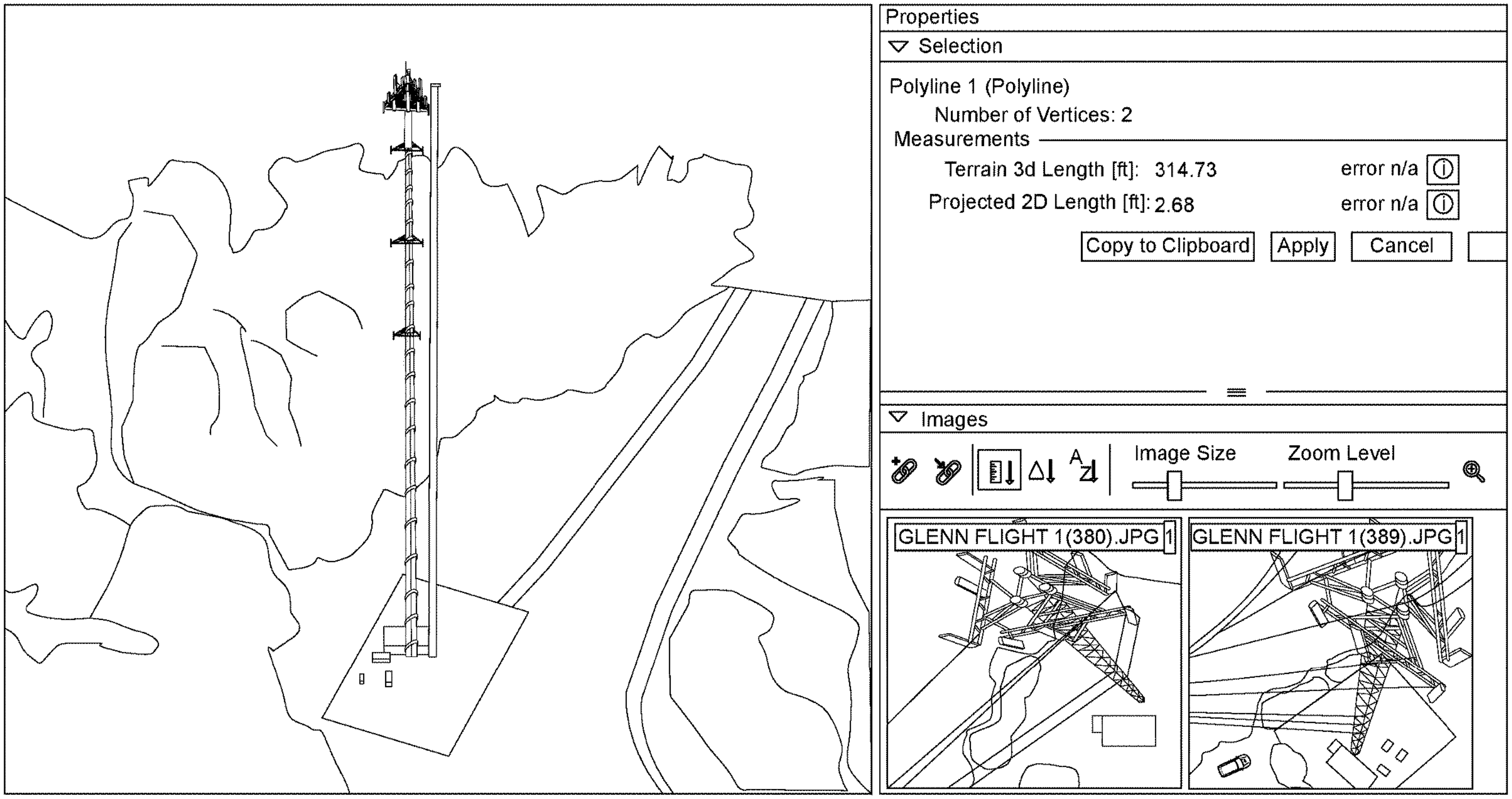


Densified Point

Number of Images Visible In: 260

Computed Position [ft]: 1974507.84, 1300874.53, 203.70

FIG. 24



Polyline 1 (Polyline)

Number of Vertices: 2

Measurements

Terrain 3d Length [ft]: 314.73 error n/a

Projected 2D Length [ft]: 2.68 error n/a

FIG. 25

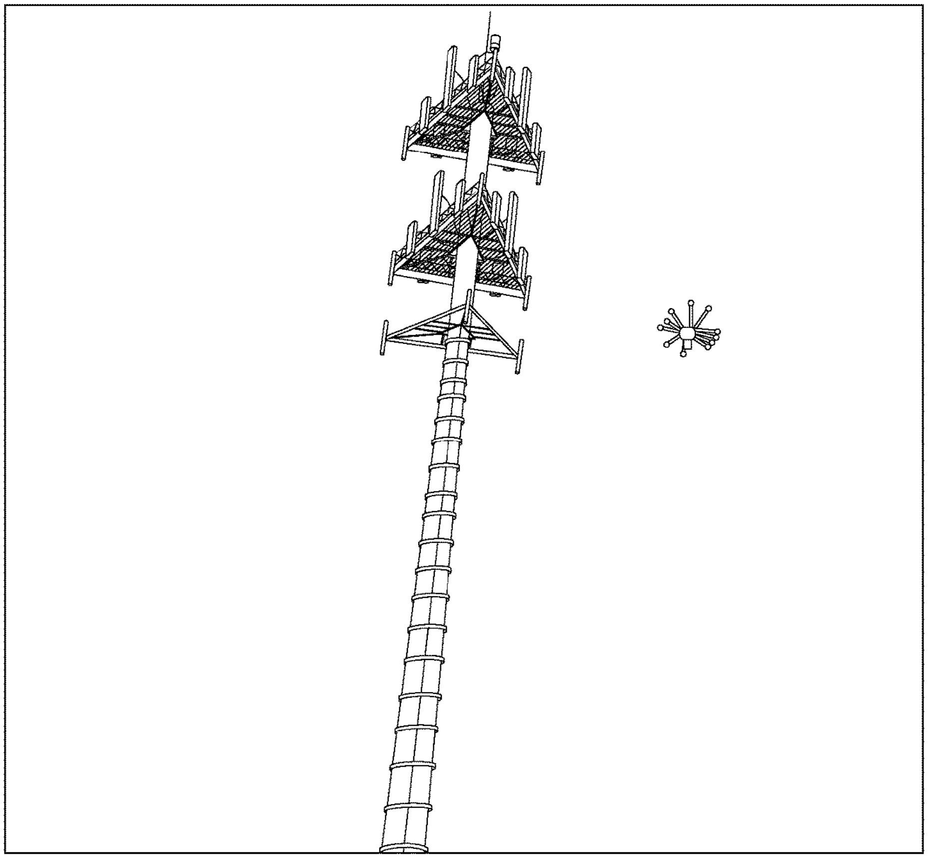
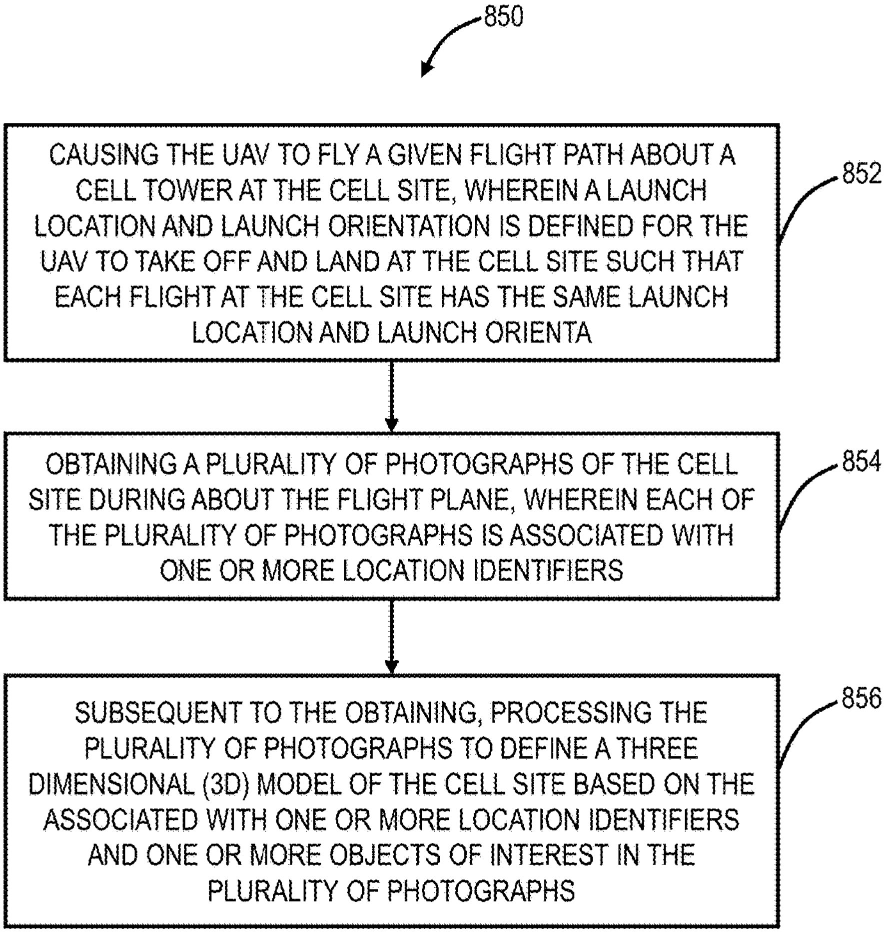


FIG. 26



CAUSING THE UAV TO FLY A GIVEN FLIGHT PATH ABOUT A CELL TOWER AT THE CELL SITE, WHEREIN A LAUNCH LOCATION AND LAUNCH ORIENTATION IS DEFINED FOR THE UAV TO TAKE OFF AND LAND AT THE CELL SITE SUCH THAT EACH FLIGHT AT THE CELL SITE HAS THE SAME LAUNCH LOCATION AND LAUNCH ORIENTA

OBTAINING A PLURALITY OF PHOTOGRAPHS OF THE CELL SITE DURING ABOUT THE FLIGHT PLANE, WHEREIN EACH OF THE PLURALITY OF PHOTOGRAPHS IS ASSOCIATED WITH ONE OR MORE LOCATION IDENTIFIERS

SUBSEQUENT TO THE OBTAINING, PROCESSING THE PLURALITY OF PHOTOGRAPHS TO DEFINE A THREE DIMENSIONAL (3D) MODEL OF THE CELL SITE BASED ON THE ASSOCIATED WITH ONE OR MORE LOCATION IDENTIFIERS AND ONE OR MORE OBJECTS OF INTEREST IN THE PLURALITY OF PHOTOGRAPHS

FIG. 27

3D MODELING OF CELL SITES AND CELL TOWERS WITH UNMANNED AERIAL VEHICLES

CROSS-REFERENCE TO RELATED APPLICATION(S)

The present patent/application is continuation-in-part of and the content of each are incorporated by reference herein:

Filing Date	Serial No.	Title
Apr. 18, 2016	15/131,460	UNMANNED AERIAL VEHICLE-BASED SYSTEMS AND METHODS ASSOCIATED WITH CELL SITES AND CELL TOWERS WITH ROBOTIC ARMS FOR PERFORMING OPERATIONS
Jun. 11, 2015	14/736,925	TETHERED UNMANNED AERIAL VEHICLE-BASED SYSTEMS AND METHODS ASSOCIATED WITH CELL SITES AND CELL TOWERS
Apr. 14, 2015	14/685,720	UNMANNED AERIAL VEHICLE-BASED SYSTEMS AND METHODS ASSOCIATED WITH CELL SITES AND CELL TOWERS

FIELD OF THE DISCLOSURE

The present disclosure relates generally to cell site systems and methods. More particularly, the present disclosure relates to three-dimensional (3D) modeling of cell sites and cell towers with unmanned aerial vehicles.

BACKGROUND OF THE DISCLOSURE

Due to the geographic coverage nature of wireless service, there are hundreds of thousands of cell towers in the United States. For example, in 2014, it was estimated that there were more than 310,000 cell towers in the United States. Cell towers can have heights up to 1,500 feet or more. There are various requirements for cell site workers (also referred to as tower climbers or transmission tower workers) to climb cell towers to perform maintenance, audit, and repair work for cellular phone and other wireless communications companies. This is both a dangerous and costly endeavor. For example, between 2003 and 2011, 50 tower climbers died working on cell sites (see, e.g., www.pbs.org/wgbh/pages/frontline/social-issues/cell-tower-deaths/in-race-for-better-cell-service-men-who-climb-towers-pay-with-their-lives/). Also, OSHA estimates that working on cell sites is 10 times more dangerous than construction work, generally (see, e.g., www.propublica.org/article/cell-tower-work-fatalities-methodology). Furthermore, the tower climbs also can lead to service disruptions caused by accidents. Thus, there is a strong desire, from both a cost and safety perspective, to reduce the number of tower climbs.

Concurrently, the use of unmanned aerial vehicles (UAV), referred to as drones, is evolving. There are limitations associated with UAVs, including emerging FAA rules and guidelines associated with their commercial use. It would be advantageous to leverage the use of UAVs to reduce tower climbs of cell towers. US 20140298181 to Rezvan describes methods and systems for performing a cell site audit remotely. However, Rezvan does not contemplate performing any activity locally at the cell site, nor various aspects of UAV use. US 20120250010 to Hannay describes aerial inspections of transmission lines using drones. However, Hannay does not contemplate performing any activity locally at the cell site, nor various aspects of constraining the UAV use. Specifically, Hannay contemplates a flight path in three dimensions along a transmission line.

Of course it would be advantageous to further utilize UAVs to actually perform operations on a cell tower. However, adding one or more robotic arms, carrying extra equipment, etc. presents a significantly complex problem in terms of UAV stabilization while in flight, i.e., counterbalancing the UAV to account for the weight and movement of the robotic arms. Research and development continues in this area, but current solutions are complex and costly, eliminating the drivers for using UAVs for performing cell tower work.

3D modeling is important for cell site operators, cell tower owners, engineers, etc. There exist current techniques to make 3D models of physical sites such as cell sites. One approach is to take hundreds or thousands of pictures and to use software techniques to combine these pictures to form a 3D model. Generally, conventional approaches for obtaining the pictures include fixed cameras at the ground with zoom capabilities or pictures via tower climbers. It would be advantageous to utilize a UAV to obtain the pictures, providing 360 degree photos from an aerial perspective. Use of aerial pictures is suggested in in US 20100231687 to Armory. However, this approach generally assumes pictures taken from a fixed perspective relative to the cell site, such as via a fixed, mounted camera and a mounted camera in an aircraft. It has been determined that such an approach is moderately inaccurate during 3D modeling and combination with software due to slight variations in location tracking capabilities of systems such as Global Positioning Satellite (GPS). It would be advantageous to adapt a UAV to take pictures and provide systems and methods for accurate 3D modeling based thereon to again leverage the advantages of UAVs over tower climbers, i.e., safety, climbing speed and overall speed, cost, etc.

BRIEF SUMMARY OF THE DISCLOSURE

In an exemplary embodiment, a method for modeling a cell site with an Unmanned Aerial Vehicle (UAV) includes causing the UAV to fly a given flight path about a cell tower at the cell site, wherein a launch location and launch orientation is defined for the UAV to take off and land at the cell site such that each flight at the cell site has the same launch location and launch orientation; obtaining a plurality of photographs of the cell site during about the flight plane, wherein each of the plurality of photographs is associated with one or more location identifiers; and, subsequent to the obtaining, processing the plurality of photographs to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs.

In another exemplary embodiment, an Unmanned Aerial Vehicle (UAV) associated with a cell site one or more rotors disposed to a body; a camera associated with the body; wireless interfaces; a processor coupled to the wireless interfaces and the camera; and memory storing instructions that, when executed, cause the processor to: process commands to cause the UAV to fly a given flight path about a cell tower at the cell site, wherein a launch location and launch orientation is defined for the UAV to take off and land at the cell site such that each flight at the cell site has the same launch location and launch orientation; obtain a plurality of photographs of the cell site during about the flight plane, wherein each of the plurality of photographs is associated with one or more location identifiers; and provide the plurality of photographs to a processing system which defines a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs.

In a further exemplary embodiment, a cell site includes a cell tower with cell site components associated therewith; a housing at the cell site storing an Unmanned Aerial Vehicle (UAV); wherein the UAV is configured to fly a given flight path about a cell tower at the cell site, wherein a launch location and launch orientation is defined for the UAV to take off and land at the cell site such that each flight at the cell site has the same launch location and launch orientation; wherein the UAV is configured to obtain a plurality of photographs of the cell site during about the flight plane, wherein each of the plurality of photographs is associated with one or more location identifiers; and wherein a processing system is configured to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs.

In an exemplary embodiment, a method with an Unmanned Aerial Vehicle (UAV) associated with a cell site includes causing the UAV to fly at or near the cell site, wherein the UAV includes one or more manipulable arms which are stationary during flight; physically connecting the UAV to a structure at the cell site and disengaging flight components associated with the UAV; and performing one or more functions via the one or more manipulable arms while the UAV is physically connected to the structure, wherein the one or more manipulable arms move while the UAV is physically connected to the structure.

In another exemplary embodiment, an Unmanned Aerial Vehicle (UAV) associated with a cell site includes one or more rotors disposed to a body; one or more manipulable arms disposed to the body; a camera associated with the body; wireless interfaces; a processor coupled to the wireless interfaces and the camera; and memory storing instructions that, when executed, cause the processor to: process commands to cause the one or more rotors to fly the UAV at or near the cell site, wherein the one or more manipulable arms are stationary during flight; process commands to cause the UAV to physically connect to a structure at the cell site and to disengage the one or more rotors; and perform one or more functions via the one or more manipulable arms while the UAV is physically connected to the structure, wherein the one or more manipulable arms move while the UAV is physically connected to the structure.

In a further exemplary embodiment, a cell site includes a cell tower with cell site components associated therewith; a housing at the cell site storing an Unmanned Aerial Vehicle (UAV), wherein the UAV includes one or more manipulable arms; wherein the UAV is configured to fly at or near the cell site responsive to a command while the one or more manipulable arms are stationary; and wherein the UAV is configured to physically connect to a structure at the cell site and to disengage flight and to subsequently perform one or more functions via the one or more manipulable arms while the UAV is physically connected to the structure, wherein the one or more manipulable arms move while the UAV is physically connected to the structure.

In an exemplary embodiment, a method with a tethered Unmanned Aerial Vehicle (UAV) associated with a cell site includes causing the UAV to fly at or near the cell site while the UAV is tethered at or near the cell site via a connection, wherein flight of the UAV at or near the cell site is constrained based on the connection; and performing one or more functions via the UAV at or near the cell site while the UAV is flying tethered at or near the cell site.

In another exemplary embodiment, a tethered Unmanned Aerial Vehicle (UAV) associated with a cell site includes one or more rotors disposed to a body, wherein the body is tethered to the cell site via a connection; a camera associated with the body; wireless interfaces; a processor coupled to the wireless interfaces and the camera; and memory storing instructions that, when executed, cause the processor to: process commands to cause the one or more rotors to fly the UAV at or near the cell site while the UAV is tethered at or near the cell site via the connection, wherein flight of the UAV at or near the cell site is constrained based on the connection; and perform one or more functions via the UAV at or near the cell site while the UAV is flying tethered at or near the cell site, utilizing one or more of the camera and the wireless interfaces.

In another exemplary embodiment, a cell site includes a cell tower with cell site components associated therewith; a housing at the cell site storing an Unmanned Aerial Vehicle (UAV), wherein the UAV is tethered at the cell site via a connection; wherein the UAV is configured to fly at or near the cell site responsive to a command while the UAV is tethered at or near the cell site via the connection, wherein flight of the UAV at or near the cell site is constrained based on the connection; and wherein the UAV is configured to perform one or more functions at or near the cell site while the UAV is flying tethered at or near the cell site, utilizing one or more of a camera and wireless interfaces.

In an exemplary embodiment, a method performed at a cell site with an Unmanned Aerial Vehicle (UAV) communicatively coupled to a controller to perform a cell site audit, without requiring a tower climb at the cell site, includes causing the UAV to fly substantially vertically up to cell site components using the controller, wherein flight of the UAV is constrained in a three-dimensional rectangle at the cell site; collecting data associated with the cell site components using the UAV; transmitting and/or storing the collected data; and processing the collected data to obtain information for the cell site audit.

In another exemplary embodiment, an Unmanned Aerial Vehicle (UAV) configured to perform a cell site audit at a cell site, without requiring a tower climb at the cell site, includes one or more rotors disposed to a body; a camera associated with the body; wireless interfaces; a processor coupled to the wireless interfaces; and memory storing instructions that, when executed, cause the processor to: receive instructions, via the wireless interfaces, related to flight at the cell site, wherein flight of the UAV is constrained in a three-dimensional rectangle at the cell site; cause the one or more rotors to operate pursuant to the instructions; operate the camera pursuant to the instructions; and transmit, via the wireless interfaces, or store, in a data store, data from the camera, for performing the cell site audit, wherein the data is processed to data to obtain information for the cell site audit.

In a further exemplary embodiment, a system configured to perform a cell site audit at a cell site, without requiring a tower climb at the cell site, includes a mobile device including: mobile device wireless interfaces communicatively coupled to wireless interfaces on an Unmanned Aerial Vehicle (UAV); a display; a processor, wherein the mobile device wireless interfaces, the display, and the processor are communicatively coupled to one another; and memory storing instructions that, when executed, cause the processor to: cause the UAV to fly substantially vertically up to cell site components through communication to the UAV wireless interfaces, wherein flight of the UAV is constrained in a three-dimensional rectangle at the cell site; receive data associated with the cell site components from the UAV wireless interfaces; display the received data to the display; and process the received data to obtain information for the cell site audit.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated and described herein with reference to the various drawings, in which like reference numbers are used to denote like system components/method steps, as appropriate, and in which:

FIG. **1** is a diagram of a side view of an exemplary cell site;

FIG. **2** is a diagram of a cell site audit performed with an unmanned aerial vehicle (UAV);

FIG. **3** is a screen diagram of a view of a graphical user interface (GUI) on a mobile device while piloting the UAV;

FIG. **4** is a perspective view of an exemplary UAV for use with the systems and methods described herein'

FIG. **5** is a block diagram of a mobile device, which may be used for the cell site audit or the like;

FIG. **6** is a flow chart of a cell site audit method utilizing the UAV and the mobile device;

FIG. **7** is a network diagram of various cell sites deployed in a geographic region;

FIG. **8** is a diagram of a tethered configuration with a UAV at a cell site;

FIG. **9** is a diagram of another tethered configuration with a UAV at a cell site;

FIG. **10** is a flowchart of a method with a tethered UAV associated with a cell site;

FIG. **11** is a diagram of a UAV with robotic arms at a cell site;

FIG. **12** is a block diagram of the UAV with robotic arms and a payload at a cell site;

FIG. **13** is a flowchart of a method with a UAV with robotic arms at a cell site;

FIG. **14** is a diagram of the cell site and an associated launch configuration and flight for the UAV to obtain photos for a 3D model of the cell site;

FIG. **15** is a satellite view of an exemplary flight of the UAV at the cell site;

FIG. **16** is a side view of an exemplary flight of the UAV at the cell site;

FIG. **17** is a logical diagram of a portion of a cell tower along with associated photos taken by the UAV at different points relative thereto;

FIG. **18** is a screen shot of a Graphic User Interface (GUI) associated with post processing photos from the UAV;

FIG. **19** is a screen shot of a 3D model constructed from a plurality of 2D photos taken from the UAV as described herein;

FIGS. **20-25** are various screen shots illustrate GUIs associated with a 3D model of a cell site based on photos taken from the UAV as described herein;

FIG. **26** is a photo of the UAV in flight at the top of a cell tower; and

FIG. **27** is a flowchart of a process for modeling a cell site with an Unmanned Aerial Vehicle (UAV).

DETAILED DESCRIPTION OF THE DISCLOSURE

Again, in various exemplary embodiments, the present disclosure relates to three-dimensional (3D) modeling of cell sites and cell towers with unmanned aerial vehicles. The present disclosure includes UAV-based systems and methods for 3D modeling and representing of cell sites and cell towers. The systems and methods include obtaining various pictures via a UAV at the cell site, flying around the cell site to obtain various different angles of various locations, tracking the various pictures (i.e., enough pictures to produce an acceptable 3D model, usually hundreds, but could be more) with location identifiers, and processing the various pictures to develop a 3D model of the cell site and the cell tower. Additionally, the systems and methods focus on precision and accuracy ensuring the location identifiers are as accurate as possible for the processing by using multiple different location tracking techniques as well as ensuring the UAV is launched from a same location and/or orientation for each flight. The same location and/or orientation, as described herein, was shown to provide more accurate location identifiers versus arbitrary location launches and orientations for different flights. Additionally, once the 3D model is constructed, the systems and methods include an application which enables cell site owners and cell site operators to "click" on any location and obtain associated photos, something extremely useful in the ongoing maintenance and operation thereof. Also, once constructed, the 3D model is capable of various measurements including height, angles, thickness, elevation, even Radio Frequency (RF), and the like.

Again, in various exemplary embodiments, the present disclosure relates to unmanned aerial vehicle (UAV)-based systems and methods associated with cell sites and cell towers, such as performing operations on cell towers via robotic arms on the UAV. To solve the issues of counterbalancing the UAV with additional weight due to carrying components and robotic arm movement, the systems and methods physically connect the UAV to the cell tower prior to deploying and operating the robotic arms. In this manner, the UAV can be flown up the cell tower with the robotic arms stationary and optionally with equipment carried therein, tethered to the cell tower, and the robotic arms can move without requiring counterbalancing of the UAV in flight. That is, the UAV is stationary and fixed to the cell tower while performing operations and maneuvers with the robotic arms. Accordingly, the systems and methods do not require complex counterbalancing techniques and provide superior stability since the UAV is not in flight while using the robotic arms. This approach allows use of commercial UAV devices without requiring complex control circuitry. Specifically, cell towers lend themselves to physical connections to the UAV. As described herein, various maintenance and installation tasks can be accomplished on a cell tower while eliminating tower climbs therefor.

Also, in additional exemplary embodiments, UAV-based systems and methods are described associated with cell sites, such as for providing cell tower audits and the like, including a tethered configuration. Various aspects of UAVs are described herein to reduce tower climbs in conjunction with cell tower audits. Additional aspects are described utilizing UAVs for other functions, such as flying from cell tower to cell tower to provide audit services and the like. Advantageously, using UAVs for cell tower audits exponentially improves the safety of cell tower audits and has been shown by Applicants to reduce costs by over 40%, as well as drastically improving audit time. With the various aspects described herein, a UAV-based audit can provide superior information and quality of such information, including a 360 degree tower view. In one aspect, the systems and methods include a constrained flight zone for the UAV such as a three-dimensional rectangle (an "ice cube" shape) about the cell tower. This constrained flight zone allows the systems and methods to operate the UAV without extensive regulations such as including extra personnel for "spotting" and requiring private pilot's licenses.

The tethered configuration includes a connection between the UAV and one or more components at a cell site. The connection can include a cable, a rope, a power cable, a communications cable, a fiber optic cable, etc., i.e., any connection with strength to constrain the UAV to the cell site. One aspect of the tethered configuration is to constrain a flight path of the UAV at the cell site. Here, the UAV may be considered part of the cell site/cell tower and not a flying vehicle that is subject to airspace regulations. Another aspect of the tethered configuration is to provide power and/or communications to the UAV. Here, the UAV can maintain extended periods of flight to provide cell site audits, wireless service, visual air traffic surveillance, etc. With the connection providing power and/or communications, the UAV can fly extended time periods. The connection can be tethered to the cell tower or some associated component, to a stake, weight, fence, building structure, etc.

§ 1.0 Exemplary Cell Site

Referring to FIG. **1**, in an exemplary embodiment, a diagram illustrates a side view of an exemplary cell site **10**. The cell site **10** includes a cell tower **12**. The cell tower **12** can be any type of elevated structure, such as 100-200 feet/30-60 meters tall. Generally, the cell tower **12** is an elevated structure for holding cell site components **14**. The cell tower **12** may also include a lighting rod **16** and a warning light **18**. Of course, there may various additional components associated with the cell tower **12** and the cell site **10** which are omitted for illustration purposes. In this exemplary embodiment, there are four sets **20**, **22**, **24**, **26** of cell site components **14**, such as for four different wireless service providers. In this example, the sets **20**, **22**, **24** include various antennas **30** for cellular service. The sets **20**, **22**, **24** are deployed in sectors, e.g. there can be three sectors for the cell site components—alpha, beta, and gamma. The antennas **30** are used to both transmit a radio signal to a mobile device and receive the signal from the mobile device. The antennas **30** are usually deployed as a single, groups of two, three or even four per sector. The higher the frequency of spectrum supported by the antenna **30**, the shorter the antenna **30**. For example, the antennas **30** may operate around 850 MHz, 1.9 GHz, and the like. The set **26** includes a microwave dish **32** which can be used to provide other types of wireless connectivity, besides cellular service. There may be other embodiments where the cell tower **12** is omitted and replaced with other types of elevated structures such as roofs, water tanks, etc.

§ 2.0 Cell Site Audits Via UAV

Referring to FIG. **2**, in an exemplary embodiment, a diagram illustrates a cell site audit **40** performed with an unmanned aerial vehicle (UAV) **50**. As described herein, the cell site audit **40** is used by service providers, third party engineering companies, tower operators, etc. to check and ensure proper installation, maintenance, and operation of the cell site components **14** and shelter or cabinet **52** equipment as well as the various interconnections between them. From a physical accessibility perspective, the cell tower **12** includes a climbing mechanism **54** for tower climbers to access the cell site components **14**. FIG. **2** includes a perspective view of the cell site **10** with the sets **20**, **26** of the cell site components **14**. The cell site components **14** for the set **20** include three sectors—alpha sector **54**, beta sector **56**, and gamma sector **58**.

In an exemplary embodiment, the UAV **50** is utilized to perform the cell site audit **40** in lieu of a tower climber access the cell site components **14** via the climbing mechanism **54**. In the cell site audit **40**, an engineer/technician is local to the cell site **10** to perform various tasks. The systems and methods described herein eliminate a need for the engineer/technician to climb the cell tower **12**. Of note, it is still important for the engineer/technician to be local to the cell site **10** as various aspects of the cell site audit **40** cannot be done remotely as described herein. Furthermore, the systems and methods described herein provide an ability for a single engineer/technician to perform the cell site audit **40** without another person handling the UAV **50** or a person with a pilot's license operating the UAV **50** as described herein.

§ 2.1 Cell Site Audit

In general, the cell site audit **40** is performed to gather information and identify a state of the cell site **10**. This is used to check the installation, maintenance, and/or operation of the cell site **10**. Various aspects of the cell site audit **40** can include, without limitation:

Verify the cell site 10 is built according to a current revision
Verify Equipment Labeling
Verify Coax Cable ("Coax") Bend Radius
Verify Coax Color Coding/Tagging
Check for Coax External Kinks & Dents
Verify Coax Ground Kits
Verify Coax Hanger/Support
Verify Coax Jumpers
Verify Coax Size
Check for Connector Stress & Distortion
Check for Connector Weatherproofing
Verify Correct Duplexers/Diplexers Installed
Verify Duplexer/Diplexer Mounting
Verify Duplexers/Diplexers Installed Correctly
Verify Fiber Paper
Verify Lacing & Tie Wraps
Check for Loose Or Cross-Threaded Coax Connectors
Verify Return ("Ret") Cables
Verify Ret Connectors
Verify Ret Grounding
Verify Ret Installation
Verify Ret Lightning Protection Unit (LPI)
Check for Shelter/Cabinet Penetrations
Verify Surge Arrestor Installation/Grounding
Verify Site Cleanliness
Verify LTE GPS Antenna Installation

Of note, the cell site audit **40** includes gathering information at and inside the shelter or cabinet **52**, on the cell tower **12**, and at the cell site components **14**. Note, it is not possible to perform all of the above items solely with the UAV **50** or remotely.

§ 3.0 Piloting the UAV at the Cell Site

It is important to note that the Federal Aviation Administration (FAA) is in the process of regulating commercial UAV (drone) operation. It is expected that these regulations would not be complete until 2016 or 2017. In terms of these regulations, commercial operation of the UAV **50**, which would include the cell site audit **40**, requires at least two people, one acting as a spotter and one with a pilot's license. These regulations, in the context of the cell site audit **40**, would make use of the UAV **50** impractical. To that end, the systems and methods described herein propose operation of the UAV **50** under FAA exemptions which allow the cell site audit **40** to occur without requiring two people and without requiring a pilot's license. Here, the UAV **50** is constrained to fly up and down at the cell site **10** and within a three-dimensional (3D) rectangle at the cell site components.

These limitations on the flight path of the UAV **50** make the use of the UAV **50** feasible at the cell site **10**.

Referring to FIG. **3**, in an exemplary embodiment, a screen diagram illustrates a view of a graphical user interface (GUI) **60** on a mobile device **100** while piloting the UAV **50**. The GUI **60** provides a real-time view to the engineer/technician piloting the UAV **50**. That is, a screen **62** provides a view from a camera on the UAV **50**. As shown in FIG. **3**, the cell site **10** is shown with the cell site components **14** in the view of the screen **62**. Also, the GUI **60** have various controls **64**, **66**. The controls **64** are used to pilot the UAV **50** and the controls **66** are used to perform functions in the cell site audit **40** and the like.

§ 3.1 FAA Regulations

The FAA is overwhelmed with applications from companies interested in flying drones, but the FAA is intent on keeping the skies safe. Currently, approved exemptions for flying drones include tight rules. Once approved, there is some level of certification for drone operators along with specific rules such as, speed limit of 100 mph, height limitations such as 400 ft, no-fly zones, day only operation, documentation, and restrictions on aerial filming. Accordingly, flight at or around cell towers is constrained and the systems and methods described herein fully comply with the relevant restrictions associated with drone flights from the FAA.

§ 4.0 Exemplary Hardware

Referring to FIG. **4**, in an exemplary embodiment, a perspective view illustrates an exemplary UAV **50** for use with the systems and methods described herein. Again, the UAV **50** may be referred to as a drone or the like. The UAV **50** may be a commercially available UAV platform that has been modified to carry specific electronic components as described herein to implement the various systems and methods. The UAV **50** includes rotors **80** attached to a body **82**. A lower frame **84** is located on a bottom portion of the body **82**, for landing the UAV **50** to rest on a flat surface and absorb impact during landing. The UAV **50** also includes a camera **86** which is used to take still photographs, video, and the like. Specifically, the camera **86** is used to provide the real-time display on the screen **62**. The UAV **50** includes various electronic components inside the body **82** and/or the camera **86** such as, without limitation, a processor, a data store, memory, a wireless interface, and the like. Also, the UAV **50** can include additional hardware, such as robotic arms or the like that allow the UAV **50** to attach/detach components for the cell site components **14**. Specifically, it is expected that the UAV **50** will get bigger and more advanced, capable of carrying significant loads, and not just a wireless camera. The present disclosure contemplates using the UAV **50** for various aspects at the cell site **10**, including participating in construction or deconstruction of the cell tower **12**, the cell site components **14**, etc.

These various components are now described with reference to a mobile device **100**. Those of ordinary skill in the art will recognize the UAV **50** can include similar components to the mobile device **100**. Of note, the UAV **50** and the mobile device **100** can be used cooperatively to perform various aspects of the cell site audit **40** described herein. In other embodiments, the UAV **50** can be operated with a controller instead of the mobile device **100**. The mobile device **100** may solely be used for real-time video from the camera **86** such as via a wireless connection (e.g., IEEE 802.11 or variants thereof). Some portions of the cell site audit **40** can be performed with the UAV **50**, some with the mobile device **100**, and others solely by the operator though visual inspection. In some embodiments, all of the aspects can be performed in the UAV **50**. In other embodiments, the UAV **50** solely relays data to the mobile device **100** which performs all of the aspects. Other embodiments are also contemplated.

Referring to FIG. **5**, in an exemplary embodiment, a block diagram illustrates a mobile device **100**, which may be used for the cell site audit **40** or the like. The mobile device **100** can be a digital device that, in terms of hardware architecture, generally includes a processor **102**, input/output (I/O) interfaces **104**, wireless interfaces **106**, a data store **108**, and memory **110**. It should be appreciated by those of ordinary skill in the art that FIG. **5** depicts the mobile device **100** in an oversimplified manner, and a practical embodiment may include additional components and suitably configured processing logic to support known or conventional operating features that are not described in detail herein. The components (**102**, **104**, **106**, **108**, and **102**) are communicatively coupled via a local interface **112**. The local interface **112** can be, for example but not limited to, one or more buses or other wired or wireless connections, as is known in the art. The local interface **112** can have additional elements, which are omitted for simplicity, such as controllers, buffers (caches), drivers, repeaters, and receivers, among many others, to enable communications. Further, the local interface **112** may include address, control, and/or data connections to enable appropriate communications among the aforementioned components.

The processor **102** is a hardware device for executing software instructions. The processor **102** can be any custom made or commercially available processor, a central processing unit (CPU), an auxiliary processor among several processors associated with the mobile device **100**, a semiconductor-based microprocessor (in the form of a microchip or chip set), or generally any device for executing software instructions. When the mobile device **100** is in operation, the processor **102** is configured to execute software stored within the memory **110**, to communicate data to and from the memory **110**, and to generally control operations of the mobile device **100** pursuant to the software instructions. In an exemplary embodiment, the processor **102** may include a mobile optimized processor such as optimized for power consumption and mobile applications. The I/O interfaces **104** can be used to receive user input from and/or for providing system output. User input can be provided via, for example, a keypad, a touch screen, a scroll ball, a scroll bar, buttons, bar code scanner, and the like. System output can be provided via a display device such as a liquid crystal display (LCD), touch screen, and the like. The I/O interfaces **104** can also include, for example, a serial port, a parallel port, a small computer system interface (SCSI), an infrared (IR) interface, a radio frequency (RF) interface, a universal serial bus (USB) interface, and the like. The I/O interfaces **104** can include a graphical user interface (GUI) that enables a user to interact with the mobile device **100**. Additionally, the I/O interfaces **104** may further include an imaging device, i.e. camera, video camera, etc.

The wireless interfaces **106** enable wireless communication to an external access device or network. Any number of suitable wireless data communication protocols, techniques, or methodologies can be supported by the wireless interfaces **106**, including, without limitation: RF; IrDA (infrared); Bluetooth; ZigBee (and other variants of the IEEE 802.15 protocol); IEEE 802.11 (any variation); IEEE 802.16 (WiMAX or any other variation); Direct Sequence Spread Spectrum; Frequency Hopping Spread Spectrum; Long Term Evolution (LTE); cellular/wireless/cordless telecommunication protocols (e.g. 3G/4G, etc.); wireless home network communication protocols; paging network protocols; magnetic induction; satellite data communication protocols; wireless hospital or health care facility network protocols such as those operating in the WMTS bands; GPRS; proprietary wireless data communication protocols such as variants of Wireless USB; and any other protocols for wireless communication. The wireless interfaces **106** can be used to communicate with the UAV **50** for command and control as well as to relay data therebetween. The data store **108** may be used to store data. The data store **108** may include any of volatile memory elements (e.g., random access memory (RAM, such as DRAM, SRAM, SDRAM, and the like)), nonvolatile memory elements (e.g., ROM, hard drive, tape, CDROM, and the like), and combinations thereof. Moreover, the data store **108** may incorporate electronic, magnetic, optical, and/or other types of storage media.

The memory **110** may include any of volatile memory elements (e.g., random access memory (RAM, such as DRAM, SRAM, SDRAM, etc.)), nonvolatile memory elements (e.g., ROM, hard drive, etc.), and combinations thereof. Moreover, the memory **110** may incorporate electronic, magnetic, optical, and/or other types of storage media. Note that the memory **110** may have a distributed architecture, where various components are situated remotely from one another, but can be accessed by the processor **102**. The software in memory **110** can include one or more software programs, each of which includes an ordered listing of executable instructions for implementing logical functions. In the example of FIG. **5**, the software in the memory **110** includes a suitable operating system (O/S) **114** and programs **116**. The operating system **114** essentially controls the execution of other computer programs, and provides scheduling, input-output control, file and data management, memory management, and communication control and related services. The programs **116** may include various applications, add-ons, etc. configured to provide end user functionality with the mobile device **100**, including performing various aspects of the systems and methods described herein.

It will be appreciated that some exemplary embodiments described herein may include one or more generic or specialized processors ("one or more processors") such as microprocessors, digital signal processors, customized processors, and field programmable gate arrays (FPGAs) and unique stored program instructions (including both software and firmware) that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of the methods and/or systems described herein. Alternatively, some or all functions may be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of the aforementioned approaches may be used. Moreover, some exemplary embodiments may be implemented as a non-transitory computer-readable storage medium having computer readable code stored thereon for programming a computer, server, appliance, device, etc. each of which may include a processor to perform methods as described and claimed herein. Examples of such computer-readable storage mediums include, but are not limited to, a hard disk, an optical storage device, a magnetic storage device, a ROM (Read Only Memory), a PROM (Programmable Read Only Memory), an EPROM (Erasable Programmable Read Only Memory), an EEPROM (Electrically Erasable Programmable Read Only Memory), Flash memory, and the like. When stored in the non-transitory computer readable medium, software can include instructions executable by a processor that, in response to such execution, cause a processor or any other circuitry to perform a set of operations, steps, methods, processes, algorithms, etc.

§ 4.1 RF Sensors in the UAV

In an exemplary embodiment, the UAV **50** can also include one or more RF sensors disposed therein. The RF sensors can be any device capable of making wireless measurements related to signals associated with the cell site components **14**, i.e., the antennas. In an exemplary embodiment, the UAV **50** can be further configured to fly around a cell zone associated with the cell site **10** to identify wireless coverage through various measurements associated with the RF sensors.

§ 5.0 Cell Site Audit with UAV and/or Mobile Device

Referring to FIG. **6**, in an exemplary embodiment, a flow chart illustrates a cell site audit method **200** utilizing the UAV **50** and the mobile device **100**. Again, in various exemplary embodiments, the cell site audit **40** can be performed with the UAV **50** and the mobile device **100**. In other exemplary embodiments, the cell site audit **40** can be performed with the UAV **50** and an associated controller. In other embodiments, the mobile device **100** is solely used to relay real-time video from the camera **86**. While the steps of the cell site audit method **200** are listed sequentially, those of ordinary skill in the art will recognize some or all of the steps may be performed in a different order. The cell site audit method **200** includes an engineer/technician at a cell site with the UAV **50** and the mobile device **100** (step **202**). Again, one aspect of the systems and methods described herein is usage of the UAV **50**, in a commercial setting, but with constraints such that only one operator is required and such that the operator does not have to hold a pilot's license. As described herein, the constraints can include flight of the UAV **50** at or near the cell site **10** only, a flight pattern up and down in a 3D rectangle at the cell tower **12**, a maximum height restriction (e.g., 500 feet or the like), and the like. For example, the cell site audit **40** is performed by one of i) a single operator flying the UAV **50** without a license or ii) two operators including one with a license and one to spot the UAV **50**.

The engineer/technician performs one or more aspects of the cell site audit **40** without the UAV **50** (step **204**). Note, there are many aspects of the cell site audit **40** as described herein. It is not possible for the UAV **50** to perform all of these items such that the engineer/technician could be remote from the cell site **10**. For example, access to the shelter or cabinet **52** for audit purposes requires the engineer/technician to be local. In this step, the engineer/technician can perform any audit functions as described herein that do not require climbing.

The engineer/technician can cause the UAV **50** to fly up the cell tower **12** or the like to view cell site components **14** (step **206**). Again, this flight can be based on the constraints, and the flight can be through a controller and/or the mobile device **100**. The UAV **50** and/or the mobile device **100** can collect data associated with the cell site components **14** (step **208**), and process the collected data to obtain information for the cell site audit **40** (step **210**). As described herein, the UAV **50** and the mobile device **100** can be configured to collect data via video and/or photographs. The engineer/technician can use this collected data to perform various aspects of the cell site audit **40** with the UAV **50** and the mobile device **100** and without a tower climb.

The foregoing descriptions detail specific aspects of the cell site audit **40** using the UAV **50** and the mobile device **100**. In these aspects, data can be collected—generally, the data is video or photographs of the cell site components **14**. The processing of the data can be automated through the UAV **50** and/or the mobile device **100** to compute certain items as described herein. Also, the processing of the data can be performed either at the cell site **10** or afterwards by the engineer/technician.

In an exemplary embodiment, the UAV **50** can be a commercial, "off-the-shelf" drone with a Wi-Fi enabled camera for the camera **86**. Here, the UAV **50** is flown with a controller pad which can include a joystick or the like. Alternatively, the UAV **50** can be flown with the mobile device **100**, such as with an app installed on the mobile device **100** configured to control the UAV **50**. The Wi-Fi enable camera is configured to communicate with the mobile device **100**—to both display real-time video and audio as well as to capture photos and/or video during the cell site audit **40** for immediate processing or for later processing to gather relevant information about the cell site components **14** for the cell site audit **40**.

In another exemplary embodiment, the UAV **50** can be a so-called "drone in a box" which is preprogrammed/configured to fly a certain route, such as based on the flight constraints described herein. The "drone in a box" can be physically transported to the cell site **10** or actually located there. The "drone in a box" can be remotely controlled as well.

§ 5.1 Antenna Down Tilt Angle

In an exemplary aspect of the cell site audit **40**, the UAV **50** and/or the mobile device **100** can be used to determine a down tilt angle of individual antennas **30** of the cell site components **14**. The down tilt angle can be determined for all of the antennas **30** in all of the sectors **54**, **56**, **58**. The down tilt angle is the mechanical (external) down tilt of the antennas **30** relative to a support bar **200**. In the cell site audit **40**, the down tilt angle is compared against an expected value, such as from a Radio Frequency (RF) data sheet, and the comparison may check to ensure the mechanical (external) down tilt is within ±1.0° of specification on the RF data sheet.

Using the UAV **50** and/or the mobile device **100**, the down tilt angle is determined from a photo taken from the camera **86**. In an exemplary embodiment, the UAV **50** and/or the mobile device **100** is configured to measure three points—two defined by the antenna **30** and one by the support bar **200** to determine the down tilt angle of the antenna **30**. For example, the down tilt angle can be determined visually from the side of the antenna **30**—measuring a triangle formed by a top of the antenna **30**, a bottom of the antenna **30**, and the support bar **200**.

§ 5.2 Antenna Plumb

In an exemplary aspect of the cell site audit **40** and similar to determining the down tilt angle, the UAV **50** and/or the mobile device **100** can be used to visually inspect the antenna **30** including its mounting brackets and associated hardware. This can be done to verify appropriate hardware installation, to verify the hardware is not loose or missing, and to verify that antenna **30** is plumb relative to the support bar **200**.

§ 5.3 Antenna Azimuth

In an exemplary aspect of the cell site audit **40**, the UAV **50** and/or the mobile device **100** can be used to verify the antenna azimuth, such as verifying the antenna azimuth is oriented within ±5° as defined on the RF data sheet. The azimuth (AZ) angle is the compass bearing, relative to true (geographic) north, of a point on the horizon directly beneath an observed object. Here, the UAV **50** and/or the mobile device **100** can include a location determining device such as a Global Positioning Satellite (GPS) measurement device. The antenna azimuth can be determined with the UAV **50** and/or the mobile device **100** using an aerial photo or the GPS measurement device.

§ 5.4 Photo Collections

As part of the cell site audit **40** generally, the UAV **50** and/or the mobile device **100** can be used to document various aspects of the cell site **10** by taking photos or video. For example, the mobile device **100** can be used to take photos or video on the ground in or around the shelter or cabinet **52** and the UAV **500** can be used to take photos or video up the cell tower **12** and of the cell site components **14**. The photos and video can be stored in any of the UAV **50**, the mobile device **100**, the cloud, etc.

In an exemplary embodiment, the UAV can also hover at the cell site **10** and provide real-time video footage back to the mobile device **100** or another location (for example, a Network Operations Center (NOC) or the like).

§ 5.5 Compound Length/Width

The UAV **50** can be used to fly over the cell site **10** to measure the overall length and width of the cell site **10** compound from overhead photos. In one aspect, the UAV **50** can use GPS positioning to detect the length and width by flying over the cell site **10**. In another aspect, the UAV **50** can take overhead photos which can be processed to determine the associated length and width of the cell site **10**.

§ 5.6 Data Capture—Cell Site Audit

The UAV **50** can be used to capture various pieces of data via the camera **86**. That is, with the UAV **50** and the mobile device **100**, the camera **86** is equivalent to the engineer/technician's own eyes, thereby eliminating the need for the engineer/technician to physically climb the tower. One important aspect of the cell site audit **40** is physically collecting various pieces of information—either to check records for consistency or to establish a record. For example, the data capture can include determining equipment module types, locations, connectivity, serial numbers, etc. from photos. The data capture can include determining physical dimensions from photos or from GPS such as the cell tower **12** height, width, depth, etc. The data capture can also include visual inspection of any aspect of the cell site **10**, cell tower **12**, cell site components **14**, etc. including, but not limited to, physical characteristics, mechanical connectivity, cable connectivity, and the like.

The data capture can also include checking the lighting rod **16** and the warning light **18** on the cell tower **12**. Also, with additional equipment on the UAV **50**, the UAV **50** can be configured to perform maintenance such as replacing the warning light **18**, etc. The data capture can also include checking maintenance status of the cell site components **14** visually as well as checking associated connection status. Another aspect of the cell site audit **40** can include checking structural integrity of the cell tower **12** and the cell site components **14** via photos from the UAV **50**.

§ 5.7 Flying the UAV at the Cell Site

In an exemplary embodiment, the UAV **50** can be programmed to automatically fly to a location and remain there without requiring the operator to control the UAV **50** in real-time, at the cell site **10**. In this scenario, the UAV **50** can be stationary at a location in the air at the cell site **10**. Here, various functionality can be incorporated in the UAV **50** as described herein. Note, this aspect leverages the ability to fly the UAV **50** commercially based on the constraints described herein. That is, the UAV **50** can be used to fly around the cell tower **12**, to gather data associated with the cell site components **14** for the various sectors **54**, **56**, **58**. Also, the UAV **50** can be used to hover around the cell tower **12**, to provide additional functionality described as follows.

§ 5.8 Video/Photo Capture—Cell Site

With the UAV **50** available to operate at the cell site **10**, the UAV **50** can also be used to capture video/photos while hovering. This application uses the UAV **50** as a mobile video camera to capture activity at or around the cell site **10** from the air. It can be used to document work at the cell site **10** or to investigate the cell site **10** responsive to problems, e.g. tower collapse. It can be used to take surveillance video of surrounding locations such as service roads leading to the cell site **10**, etc.

§ 5.9 Wireless Service Via the UAV

Again, with the ability to fly at the cell site **10**, subject to the constraints, the UAV **50** can be used to provide temporary or even permanent wireless service at the cell site. This is performed with the addition of wireless service-related components to the UAV **50**. In the temporary mode, the UAV **50** can be used to provide service over a short time period, such as responding to an outage or other disaster affecting the cell site **10**. Here, an operator can cause the UAV **50** to fly where the cell site components **14** are and provide such service. The UAV **50** can be equipped with wireless antennas to provide cell service, Wireless Local Area Network (WLAN) service, or the like. The UAV **50** can effectively operate as a temporary tower or small cell as needed.

In the permanent mode, the UAV **50** (along with other UAVs **50**) can constantly be in the air at the cell site **10** providing wireless service. This can be done similar to the temporary mode, but over a longer time period. The UAV **50** can be replaced over a predetermined time to refuel or the like. The replacement can be another UAV **50**. The UAV **50** can effectively operate as a permanent tower or small cell as needed.

§ 6.0 Flying the UAV from Cell Site to Another Cell Site

As described herein, the flight constraints include operating the UAV **50** vertically in a defined 3D rectangle at the cell site **10**. In another exemplary embodiment, the flight constraints can be expanded to allow the 3D rectangle at the cell site **10** as well as horizontal operation between adjacent cell sites **10**. Referring to FIG. **7**, in an exemplary embodiment, a network diagram illustrates various cell sites **10***a*-**10***e* deployed in a geographic region **300**. In an exemplary embodiment, the UAV **50** is configured to operate as described herein, such as in FIG. **2**, in the vertical 3D rectangular flight pattern, as well as in a horizontal flight pattern between adjacent cell sites **10**. Here, the UAV **50** is cleared to fly, without the commercial regulations, between the adjacent cell sites **10**.

In this manner, the UAV **50** can be used to perform the cell site audits **40** at multiple locations—note, the UAV **50** does not need to land and physically be transported to the adjacent cell sites **10**. Additionally, the fact that the FAA will allow exemptions to fly the UAV **50** at the cell site **10** and between adjacent cell sites **10** can create an interconnected mesh network of allowable flight paths for the UAV **50**. Here, the UAV **50** can be used for other purposes besides those related to the cell site **10**. That is, the UAV **50** can be flown in any application, independent of the cell sites **10**, but without requiring FAA regulation. The applications can include, without limitation, a drone delivery network, a drone surveillance network, and the like.

As shown in FIG. **7**, the UAV **50**, at the cell site **10***a*, can be flown to any of the other cell sites **10***b*-**10***e* along flight paths **302**. Due to the fact that cell sites **10** are numerous and diversely deployed in the geographic region **300**, an ability to fly the UAV **50** at the cell sites **10** and between adjacent cell sites **10** creates an opportunity to fly the UAV **50** across the geographic region **300**, for numerous applications.

§ 7.0 UAV and Cell Towers

Additionally, the systems and methods describe herein contemplate practically any activity at the cell site **10** using the UAV **50** in lieu of a tower climb. This can include, without limitation, any tower audit work with the UAV **50**, any tower warranty work with the UAV **50**, any tower operational ready work with the UAV **50**, any tower construction with the UAV **50**, any tower decommissioning/deconstruction with the UAV **50**, any tower modifications with the UAV **50**, and the like.

§ 8.0 Tethered UAV Systems and Methods

Referring to FIGS. **8** and **9**, in an exemplary embodiment, diagrams illustrate a cell site **10** for illustrating the UAV **50** and associated tethered UAV systems and methods. Specifically, FIGS. **8** and **9** is similar to FIG. **2**, but here, the UAV **50** is tethered at or near the cell site **10** via a connection **400**. The connection **400** can include a cable, a rope, a power cable, a communications cable, a fiber optic cable, etc., i.e., any connection with strength to constrain the UAV **50** to the cell site **10**. In an exemplary embodiment in FIG. **8**, the connection **400** is tethered to the top of the cell tower **12**, such as at the cell site components **14** or at one of the alpha sector **54**, beta sector **56**, and gamma sector **58**. In another exemplary embodiment in FIG. **8**, the connection **400** is tethered to the cell tower **12** itself, such as at any point between the base and the top of the cell tower **12**. In a further exemplary embodiment in FIG. **8**, the connection **400** is tethered to the bottom of the cell site **10**, such as at the shelter or cabinet **52** or a base of the cell tower **12**. Specifically, in FIG. **8**, the tethered configuration includes the connection **400** coupled to some part of the cell tower **12** or the like.

In FIG. **9**, the tethered configuration includes the connection **400** coupled to something that is not part of the cell tower **12**, such as a connection point **401**, i.e., in FIG. **9**, the UAV **50** is tethered at or near the cell site **10** and, in FIG. **8**, the UAV **50** is tethered at the cell tower **12**. In various exemplary embodiments, the connection point **401** can include, without limitation, a stake, a pole, a weight, a fence, a communications device, a wireless radio, a building or other structure, or any other device or object at or near the cell site **12**. As described herein, the UAV **50** is in a tethered configuration where the UAV **50** is coupled at or near the cell site **10** via the connection **400**.

In an exemplary embodiment, the UAV **50** can be housed or located at or near the cell site **10**, connected via the connection **400**, and stored in housings **402**, **404**, for example. The housings **402**, **404** are shown for illustration purposes, and different locations are also contemplated. The housing **402** is on the cell tower **12**, and the housing **404** is at or part of the shelter or cabinet **52**. In operation, the UAV **50** is configured to selectively enter/exit the housing **402**, **404**. The connection **400** can be tethered to or near the housing **402**, **404**. The housing **402**, **404** can include a door that selectively opens/closes. Alternatively, the housing **402**, **404** includes an opening where the UAV **50** enters and exits. The housing **402**, **404** can be used to store the UAV **50** while not in operation.

One unique aspect of the tethered configuration described herein, i.e., the UAV **50** with the connection **400**, is that the UAV **50** can now be viewed as an attached device to the cell site **10**, and not a free-flying drone. Advantageously, such a configuration can avoid airspace regulations or restrictions.

Furthermore, with the connection **400** providing power and/or data connectivity, the UAV **50** contemplates extended periods of time for operation.

As costs decrease, it is feasible to deploy the UAV **50** with the connections **400** and optionally the housing **402**, **404** at all cell sites **10**. The UAV **50** with the connection **400** contemplates implementing all of the same functionality described herein with respect to FIGS. **1-6**. Specifically, the UAV **50** with the connection **400** can be used to perform the cell site audit **40** and the like as well as other features. Also, the UAV **50** with the connection **400** is ideal to act as a wireless access point for wireless service. Here, the connection **400** can provide data and/or power, and be used for 1) additional capacity as needed or 2) a protection antenna to support active components in the cell site components **14** that fail. The UAV **50** with the connection **400** can be used to support overflow capacity as well as needed, providing LTE, WLAN, WiMAX, or any other wireless connectivity. Alternatively, the UAV **50** can be used as an alternative service provider to provide wireless access at the cell site **10** without requiring antennas on the cell tower **12**.

Referring to FIG. **8**, in an exemplary embodiment, a flowchart illustrates a method **500** with a tethered Unmanned Aerial Vehicle (UAV) associated with a cell site. The method **500** includes causing the UAV to fly at or near the cell site while the UAV is tethered at or near the cell site via a connection, wherein flight of the UAV at or near the cell site is constrained based on the connection (step **502**); and performing one or more functions via the UAV at or near the cell site while the UAV is flying tethered at or near the cell site (step **504**).

The method **500** can further include transferring power and/or data to and from the UAV via the connection (step **506**). The connection can include one or more of a cable, a rope, a power cable, a communications cable, and a fiber optic cable. The one or more functions can include functions related to a cell site audit. The one or more functions can include functions related to providing wireless service via the UAV at the cell site, wherein data and/or power is transferred between the UAV and the cell site to perform the wireless service. The one or more functions can include providing visual air traffic control via one or more cameras on the UAV. The method **500** can further include storing the UAV at the cell site in a housing while the UAV is not in use. The UAV can be configured to fly extended periods at the cell site utilizing power from the connection, where the extended periods are longer than if the UAV did not have power from the connection. The connection can be configured to constrain a flight path of the UAV at the cell site.

In another exemplary embodiment, a tethered Unmanned Aerial Vehicle (UAV) associated with a cell site includes one or more rotors disposed to a body, wherein the body is tethered to the cell site via a connection; a camera associated with the body; wireless interfaces; a processor coupled to the wireless interfaces and the camera; and memory storing instructions that, when executed, cause the processor to: process commands to cause the one or more rotors to fly the UAV at the cell site while the UAV is tethered to the cell site via the connection, wherein flight of the UAV at the cell site is constrained based on the connection; and perform one or more functions via the UAV at the cell site while the UAV is flying tethered to the cell site, utilizing one or more of the camera and the wireless interfaces.

§ 8.1 Tethered UAV Systems and Methods—Visual Air Traffic Control

In an exemplary embodiment, the tethered UAV **50** can be configured to provide visual air traffic control such as for other UAVs or drones. Here, various tethered UAVs **50** can be deployed across a geographic region at various cell sites **10** and each UAV **50** can have one or more cameras that can provide a 360 degree view around the cell site **10**. This configuration essentially creates a drone air traffic control system that could be monitored and controlled by Network Control Center (NOC). Specifically, the UAV **50** can be communicatively coupled to the NOC, such as via the connection **400**. The NOC can provide the video feeds of other drones to third parties (e.g., Amazon) and other drone users to comply with current FAA regulations that require eyes on drones at all times.

§ 9.0 UAV Systems and Methods Using Robotic Arms or the Like

Referring to FIGS. **11** and **12**, in an exemplary embodiment, diagrams illustrate a cell site **10** for illustrating the UAV **50** and associated UAV systems and methods with robotic arms for performing operations associated with the cell site components **14**. Specifically, FIGS. **11** and **12** is similar to FIG. **2** (and FIGS. **8** and **9**), but here, the UAV **50** is equipped with one or more robotic arms **600** for carrying payload **602** and/or performing operations associated with the cell site components **14** on the cell tower **12**. Since the robotic arms **600** and the payload **602** add weight and complexity when maneuvering, the systems and methods include a connection **604** between the UAV **50** and the cell tower **12** which physically supports the UAV **50** at the cell site components **14**. In this manner, there are no counterbalance requirements for the UAV **50** for the robotic arms **600** and the payload **602**. In another exemplary embodiment, the connection **604** can also provide power to the UAV **50** in addition to physically supporting the UAV **50**. That is, the connection **604** is adapted to provide power to the UAV **50** when connected thereto. Specifically, the robotic arms **600** could require a large amount of power, which can come from a power source connected through the connection **604** to the UAV. In an exemplary embodiment, the UAV **50**, once physically connected to the connection **604**, can shut off the flight and local power components and operate the robotic arms **600** via power from the connection **604**.

In another exemplary embodiment, the UAV **50** with the robotic arms **600** can utilize the tethered configuration where the UAV **50** is coupled at or near the cell site **10** via the connection **400**. Here, the UAV **50** can use both the connection **400** for a tether and the connection **604** for physical support/stability when at the cell tower **12** where operations are needed. Here, the connection **400** can be configured to provide power to the UAV **50** as well. The UAV **50** can also fly up the connection **400** from the ground that supplies power and any other functions such as a video feed up or down. The tethered UAV **500** attaches itself to the cell tower **12** via the connection **604**, shuts off rotors, engages the robotic arms **600** and then does work, but in this case the power for those robotic arms **600** as well as the rotors comes from a power feed in the connection **400** that is going down to the ground. The UAV **50** also may or may not have a battery and it may or may not be used.

The UAV **50** with the robotic arms **600** is configured to fly up the cell tower **12**, with or without the payload **602**. For example, with the payload **602**, the UAV **50** can be used to bring components to the cell site components **14**, flying up the cell tower **12**. Without the payload **602**, the UAV **50** is flown to the top with the robotic arms **600** for performing operations on the cell tower **12** and the cell site components **14**. In both cases, the UAV **50** is configured to fly up the cell tower **12**, including using all of the constraints described herein. During flight, the UAV **50** with the robotic arms **600** and with or without the payload **602** does not have a counterbalance issue because the robotic arms **600** and the payload **602** are fixed, i.e., stationary. That is, the UAV **50** flies without movement of the robotic arms **600** or the payload **603** during the flight.

Once the UAV **50** reaches a desired location on the cell tower **12**, the UAV **50** is configured to physically connect via the connection **604** to the cell tower **12**, the cell site components **14**, or the like. Specifically, via the connection **604**, the UAV **50** is configured to be physically supported without the rotors **80** or the like operating. That is, via the connection **604**, the UAV **50** is physically supporting without flying, thereby eliminating the counterbalancing problems. Once the connection **604** is established and the UAV **50** flight components are disengaged, the robotic arms **600** and the payload **602** can be moved, manipulated, etc. without having balancing problems that have to be compensated by the flight components. This is because the connection **604** bears the weight of the UAV **50**, allowing any movement by the robotic arms **600** and/or the payload **602**.

In an exemplary embodiment, the connection **604** includes a grappling arm that extends from the UAV **50** and physically attaches to the cell tower **12**, such as a grappling hook or the like. In another exemplary embodiment, the connection **604** includes an arm located on the cell tower **12** that physically connects to a connection point in the UAV **50**. Of course, the systems and methods contemplate various connection techniques for the connection **604**. The connection **604** has to be strong enough to support the weight of the UAV **50**, the robotic arms **600**, and the payload **602**.

In an exemplary embodiment, the UAV **50** can carry the payload **602** up the cell tower **12**. The payload **602** can include wireless components, cables, nuts/bolts, antennas, supports, braces, lighting rods, lighting, electronics, RF equipment, combinations thereof, and the like. That is, the payload **602** can be anything associated with the cell site components **14**. With the robotic arms **600**, the UAV **500** can be used to perform operations associated with the payload **602**. The operations can include, without limitation, installing cables, installing nuts/bolts to structures or components, installing antennas, installing supports or braces, installing lighting rods, installing electronic or RF equipment, etc.

In another exemplary embodiment, the UAV **50** does not include the payload **602** and instead uses the robotic arms **600** to perform operations on existing cell site components **14**. Here, the UAV **50** is flown up the cell site **12** and connected to the connection **604**. Once connected and the flight components disengaged, the UAV **50** can include manipulation of the robotic arms **600** to perform operations on the cell site components **14**. The operations can include, without limitation, manipulating cables, removing/tightening nuts/bolts to structures or components, adjusting antennas, adjusting lighting rods, replacing bulbs in lighting, opening/closing electronic or RF equipment, etc.

Referring to FIG. **13**, in an exemplary embodiment, a flowchart illustrates a method **700** with a UAV with robotic arms at a cell site. The method **700** contemplates operation with the UAV **50** with the robotic arms **600** and optionally with the payload **602**. The method **700** includes causing the UAV to fly at or near the cell site, wherein the UAV comprises one or more manipulable arms which are stationary during flight (step **702**); physically connecting the UAV to a structure at the cell site and disengaging flight components associated with the UAV (step **704**); and performing one or more functions via the one or more manipulable arms while the UAV is physically connected to the structure, wherein the one or more manipulable arms move while the UAV is physically connected to the structure (step **706**). The method **700** can further include utilizing the one or more manipulable arms to provide payload to a cell tower at the cell site, wherein the payload is stationary in the one or more manipulable arms during flight (step **708**). The payload can include any of wireless components, cables, nuts/bolts, antennas, supports, braces, lighting rods, lighting, electronics, and combinations thereof. The method **700** can further include utilizing the one or more manipulable arms to perform operations on a cell tower at the cell site (step **710**). The operations can include any of installing wireless components, installing cables, installing nuts/bolts, installing antennas, installing supports, installing braces, installing lighting rods, installing lighting, installing electronics, and combinations thereof. The physically connecting can include extending a grappling arm from the UAV to attach to the structure. The physically connecting can include connecting the UAV to an arm extending from the structure which is connectable to the UAV. The physically connecting can be via a connection which bears weight of the UAV, enabling movement of the one or more manipulable arms without requiring counterbalancing of the UAV due to the movement while the UAV is in flight.

§ 10.0 Cell Site Operations

There are generally two entities associated with cell sites—cell site owners and cell site operators. Generally, cell site owners can be viewed as real estate property owners and managers. Typical cell site owners may have a vast number of cell sites, such as tens of thousands, geographically dispersed. The cell site owners are generally responsible for the real estate, ingress and egress, structures on site, the cell tower itself, etc. Cell site operators generally include wireless service providers who generally lease space on the cell tower and in the structures for antennas and associated wireless backhaul equipment. There are other entities that may be associated with cell sites as well including engineering firms, installation contractors, and the like. All of these entities have a need for the various UAV-based systems and methods described herein. Specifically, cell site owners can use the systems and methods for real estate management functions, audit functions, etc. Cell site operators can use the systems and methods for equipment audits, troubleshooting, site engineering, etc. Of course, the systems and methods described herein can be provided by an engineering firm or the like contracted to any of the above entities or the like. The systems and methods described herein provide these entities time savings, increased safety, better accuracy, lower cost, and the like.

§ 11.0 3D Modeling Systems and Methods with UAVs

Referring to FIG. **14**, in an exemplary embodiment, a diagram illustrates the cell site **10** and an associated launch configuration and flight for the UAV **50** to obtain photos for a 3D model of the cell site **10**. Again, the cell site **10**, the cell tower **12**, the cell site components **14**, etc. are as described herein. To develop a 3D model, the UAV **50** is configured to take various photos during flight, at different angles, orientations, heights, etc. to develop a 360 degree view. For post processing, it is important to accurately differentiate between different photos. In various exemplary embodiments, the systems and methods utilize accurate location tracking for each photo taken. It is important for accurate correlation between photos to enable construction of a 3D model from a plurality of 2D photos. The photos can all include multiple location identifiers (i.e., where the photo was taken from, height and exact location). In an exemplary embodiment, the photos can each include at least two distinct location identifiers, such as from GPS or GLO-

NASS. GLONASS is a "GLObal NAvigation Satellite System" which is a space-based satellite navigation system operating in the radionavigation-satellite service and used by the Russian Aerospace Defence Forces. It provides an alternative to GPS and is the second alternative navigational system in operation with global coverage and of comparable precision. The location identifiers are tagged or embedded to each photo and indicative of the location of the UAV **50** where and when the photo was taken. These location identifiers are used with objects of interest identified in the photo during post processing to create the 3D model.

In fact, it was determined that location identifier accuracy is very important in the post processing for creating the 3D model. One such determination was that there are slight inaccuracies in the location identifiers when the UAV **50** is launched from a different location and/or orientation. Thus, to provide further accuracy for the location identifiers, each flight of the UAV **50** is constrained to land and depart from a same location and orientation. For example, future flights of the same cell site **10** or additional flights at the same time when the UAV **50** lands and, e.g., has a battery change. To ensure the same location and/or orientation in subsequent flights at the cell site **10**, a zone indicator **800** is set at the cell site **10**, such as on the ground via some marking (e.g., chalk, rope, white powder, etc.). Each flight at the cell site **10** for purposes of obtaining photos for 3D modeling is done using the zone indicator **800** to land and launch the UAV **50**. Based on operations, it was determined that using conventional UAVs **50**, the zone indicator **800** provides significant more accuracy in location identifier readings. Accordingly, the photos are accurately identified relative to one another and able to create an extremely accurate 3D model of all physical features of the cell site **10**. Thus, in an exemplary embodiment, all UAV **50** flights are from a same launch point and orientation to avoid calibration issues with any location identifier technique. The zone indicator **800** can also be marked on the 3D model for future flights at the cell site **10**. Thus, the use of the zone indicator **800** for the same launch location and orientation along with the multiple location indicators provide more precision in the coordinates for the UAV **50** to correlate the photos.

Note, in other exemplary embodiments, the zone indicator **800** may be omitted or the UAV **50** can launch from additional points, such that the data used for the 3D model is only based on a single flight. The zone indicator **800** is advantageous when data is collected over time or when there are landings in a flight.

Once the zone indicator **800** is established, the UAV **50** is placed therein in a specific orientation (orientation is arbitrary so long as the same orientation is continually maintained). The orientation refers to which way the UAV **50** is facing at launch and landing. Once the UAV **50** is in the zone indicator **800**, the UAV **50** can be flown up (denoted by line **802**) the cell tower **12**. Note, the UAV **50** can use the aforementioned flight constraints to conform to FAA regulations or exemptions. Once at a certain height and certain distance from the cell tower **12** and the cell site components **14**, the UAV **50** can take a circular or 360 degree flight pattern about the cell tower **12**, including flying up as well as around the cell tower **12** (denoted by line **804**).

During the flight, the UAV **50** is configured to take various photos of different aspects of the cell site **10** including the cell tower **12**, the cell site components **14**, as well as surrounding area. These photos are each tagged or embedded with multiple location identifiers. It has also been determined that the UAV **50** should be flown at a certain distance based on its camera capabilities to obtain the optimal photos, i.e., not too close or too far from objects of interest. The UAV **50** in a given flight can take hundreds or even thousands of photos, each with the appropriate location identifiers. For an accurate 3D model, at least hundreds of photos are required. The UAV **50** can be configured to automatically take pictures are given intervals during the flight and the flight can be a preprogrammed trajectory around the cell site **10**. Alternatively, the photos can be manually taken based on operator commands. Of course, a combination is also contemplated. In another exemplary embodiment, the UAV **50** can include preprocessing capabilities which monitor photos taken to determine a threshold after which enough photos have been taken to accurately construct the 3D model.

Referring to FIG. **15**, in an exemplary embodiment, a satellite view illustrates an exemplary flight of the UAV **50** at the cell site **10**. Note, photos are taken at locations marked with circles in the satellite view. Note, the flight of the UAV **50** can be solely to construct the 3D model or as part of the cell site audit **40** described herein. Also note, the exemplary flight allows photos at different locations, angles, orientations, etc. such that the 3D model not only includes the cell tower **12**, but also the surrounding geography.

Referring to FIG. **16**, in an exemplary embodiment, a side view illustrates an exemplary flight of the UAV **50** at the cell site **10**. Similar to FIG. **15**, FIG. **16** shows circles in the side view at locations where photos were taken. Note, photos are taken at different elevations, orientations, angles, and locations.

The photos are stored locally in the UAV **50** and/or transmitted wirelessly to a mobile device, controller, server, etc. Once the flight is complete and the photos are provided to an external device from the UAV **50** (e.g., mobile device, controller, server, cloud service, or the like), post processing occurs to combine the photos or "stitch" them together to construct the 3D model. While described separately, the post processing could occur in the UAV **50** provided its computing power is capable.

Referring to FIG. **17**, in an exemplary embodiment, a logical diagram illustrates a portion of a cell tower **12** along with associated photos taken by the UAV **50** at different points relative thereto. Specifically, various 2D photos are logically shown at different locations relative to the cell tower **12** to illustrate the location identifiers and the stitching together of the photos.

Referring to FIG. **18**, in an exemplary embodiment, a screen shot illustrates a Graphic User Interface (GUI) associated with post processing photos from the UAV **50**. Again, once the UAV **50** has completed taking photos of the cell site **10**, the photos are post processed to form a 3D model. The systems and methods contemplate any software program capable of performing photogrammetry. In the example of FIG. **18**, there are 128 total photos. The post processing includes identifying visible points across the multiple points, i.e., objects of interest. For example, the objects of interest can be any of the cell site components **14**, such as antennas. The post processing identifies the same object of interest across different photos, with their corresponding location identifiers, and builds a 3D model based on multiple 2D photos.

Referring to FIG. **19**, in an exemplary embodiment, a screen shot illustrates a 3D model constructed from a plurality of 2D photos taken from the UAV **50** as described herein. Note, the 3D model can be displayed on a computer or another type of processing device, such as via an application, a Web browser, or the like. The 3D model supports zoom, pan, tilt, etc.

Referring to FIGS. **20-25**, in various exemplary embodiments, various screen shots illustrate GUIs associated with a 3D model of a cell site based on photos taken from the UAV **50** as described herein. FIG. **20** is a GUI illustrating an exemplary measurement of an object, i.e., the cell tower **12**, in the 3D model. Specifically, using a point and click operation, one can click on two points such as the top and bottom of the cell tower and the 3D model can provide a measurement, e.g. 175' in this example. FIG. **21** illustrates a close up view of a cell site component **14** such as an antenna and a similar measurement made thereon using point and click, e.g. 4.55' in this example. FIGS. **22** and **23** illustrate an aerial view in the 3D model showing surrounding geography around the cell site **10**. From these views, the cell tower **12** is illustrated with the surrounding environment including the structures, access road, fall line, etc. Specifically, the 3D model can assist in determining a fall line which is anywhere in the surroundings of the cell site **10** where the cell tower **12** may fall. Appropriate considerations can be made based thereon.

FIGS. **24** and **25** illustrate the 3D model and associated photos on the right side. One useful aspect of the 3D model GUI is an ability to click anywhere on the 3D model and bring up corresponding 2D photos. Here, an operator can click anywhere and bring up full sized photos of the area. Thus, with the systems and methods described herein, the 3D model can measure and map the cell site **10** and surrounding geography along with the cell tower **12**, the cell site components **14**, etc. to form a comprehensive 3D model. There are various uses of the 3D model to perform cell site audits including checking tower grounding; sizing and placement of antennas, piping, and other cell site components **14**; providing engineering drawings; determining characteristics such as antenna azimuths; and the like.

Referring to FIG. **26**, in an exemplary embodiment, a photo illustrates the UAV **50** in flight at the top of a cell tower **12**. As described herein, it was determined that the optimum distance to photograph the cell site components **14** is about 10' to 40' distance.

Referring to FIG. **27**, in an exemplary embodiment, a flowchart illustrates a process **850** for modeling a cell site with an Unmanned Aerial Vehicle (UAV). The process **850** includes causing the UAV to fly a given flight path about a cell tower at the cell site, wherein a launch location and launch orientation is defined for the UAV to take off and land at the cell site such that each flight at the cell site has the same launch location and launch orientation (step **852**); obtaining a plurality of photographs of the cell site during about the flight plane, wherein each of the plurality of photographs is associated with one or more location identifiers (step **854**); and, subsequent to the obtaining, processing the plurality of photographs to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs (step **856**).

The process **850** can further include landing the UAV at the launch location in the launch orientation; performing one or more operations on the UAV, such as changing a battery; and relaunching the UAV from the launch location in the launch orientation to obtain additional photographs. The one or more location identifiers can include at least two location identifiers including Global Positioning Satellite (GPS) and GLObal NAvigation Satellite System (GLONASS). The flight plane can be constrained to an optimum distance from the cell tower. The plurality of photographs can be obtained automatically during the flight plan while concurrently performing a cell site audit of the cell site. The process **850** can further include providing a graphical user interface (GUI) of the 3D model; and using the GUI to perform a cell site audit. The process **850** can further include providing a graphical user interface (GUI) of the 3D model; and using the GUI to measure various components at the cell site. The process **850** can further include providing a graphical user interface (GUI) of the 3D model; and using the GUI to obtain photographs of the various components at the cell site.

Although the present disclosure has been illustrated and described herein with reference to preferred embodiments and specific examples thereof, it will be readily apparent to those of ordinary skill in the art that other embodiments and examples may perform similar functions and/or achieve like results. All such equivalent embodiments and examples are within the spirit and scope of the present disclosure, are contemplated thereby, and are intended to be covered by the following claims.

What is claimed is:

1. A method for modeling a cell site with an Unmanned Aerial Vehicle (UAV), the method comprising:

causing the UAV to fly a given flight path about a cell tower at the cell site, wherein the UAV takes a plurality of flights about the cell tower and a launch location and launch orientation is defined for the UAV to take off and land at the cell site via a zone indicator at the cell site which marks a location on the ground such that each flight of the plurality of flights has the same launch location at the cell site and launch orientation where the UAV is facing during the take off;

obtaining a plurality of photographs of the cell site during the plurality of flights, wherein each of the plurality of photographs is associated with one or more location identifiers;

subsequent to the obtaining, processing the plurality of photographs to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs, wherein the 3D model further includes the zone indicator for future flights; and

subsequent to creation of the 3D model, relaunching the UAV from the launch location based on the zone indicator in the launch orientation to obtain updated photographs and updating the 3D model with the updated photographs.

2. The method of claim **1**, further comprising:

landing the UAV at the launch location in the launch orientation;

performing one or more operations on the UAV; and

relaunching the UAV from the launch location in the launch orientation to obtain additional photographs.

3. The method of claim **1**, wherein the one or more location identifiers comprise at least two location identifiers comprising Global Positioning Satellite (GPS) and GLObal NAvigation Satellite System (GLONASS).

4. The method of claim **1**, wherein the flight plane is constrained to an optimum distance from the cell tower.

5. The method of claim **1**, wherein the plurality of photographs are obtained automatically during the flight plan while concurrently performing a cell site audit of the cell site.

6. The method of claim **1**, further comprising:

providing a graphical user interface (GUI) of the 3D model; and

using the GUI to perform a cell site audit.

7. The method of claim **1**, further comprising:

providing a graphical user interface (GUI) of the 3D model; and

using the GUI to measure various components at the cell site.

8. The method of claim **1**, further comprising:

providing a graphical user interface (GUI) of the 3D model; and

using the GUI to obtain photographs of the various components at the cell site.

9. An Unmanned Aerial Vehicle (UAV) associated with a cell site, the UAV comprising:

one or more rotors disposed to a body;

a camera associated with the body;

wireless interfaces;

a processor coupled to the wireless interfaces and the camera; and

memory storing instructions that, when executed, cause the processor to:

process commands to cause the UAV to fly a given flight path about a cell tower at the cell site, wherein the UAV takes a plurality of flights about the cell tower and a launch location and launch orientation is defined for the UAV to take off and land at the cell site via a zone indicator at the cell site which marks a location on the ground such that each flight of the plurality of flights has the same launch location at the cell site and launch orientation where the UAV is facing during the take off;

obtain a plurality of photographs of the cell site during the plurality of flights, wherein each of the plurality of photographs is associated with one or more location identifiers;

provide the plurality of photographs to a processing system which defines a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs, wherein the 3D model further includes the zone indicator for future flights; and; and

subsequent to creation of the 3D model, obtain updated photographs where the UAV is relaunched from the launch location based on the zone indicator in the launch orientation for the updated photographs and update the 3D model with the updated photographs.

10. The UAV of claim **9**, wherein the UAV lands at the launch location in the launch orientation, one or more operations are performed on the UAV, and the UAV is relaunched from the launch location in the launch orientation to obtain additional photographs.

11. The UAV of claim **9**, wherein the one or more location identifiers comprise at least two location identifiers comprising Global Positioning Satellite (GPS) and GLObal NAvigation Satellite System (GLONASS).

12. The UAV of claim **9**, wherein the flight plane is constrained to an optimum distance from the cell tower.

13. The UAV of claim **9**, wherein the plurality of photographs are obtained automatically during the flight plan while concurrently performing a cell site audit of the cell site.

14. The UAV of claim **9**, wherein the processing system provides a graphical user interface (GUI) of the 3D model, and the GUI is utilized to perform a cell site audit.

15. The UAV of claim **9**, wherein the processing system provides a graphical user interface (GUI) of the 3D model, and the GUI is utilized to measure various components at the cell site.

16. The UAV of claim **9**, wherein the processing system provides a graphical user interface (GUI) of the 3D model, and the GUI is utilized to obtain photographs of the various components at the cell site.

17. A cell site, comprising:

a cell tower with cell site components associated therewith;

a housing at the cell site storing an Unmanned Aerial Vehicle (UAV);

wherein the UAV is configured to fly a given flight path about a cell tower at the cell site, wherein the UAV takes a plurality of flights about the cell tower and a launch location and launch orientation is defined for the UAV to take off and land at the cell site via a zone indicator at the cell site which marks a location on the ground such that each flight of the plurality of flights has the same launch location at the cell site and launch orientation where the UAV is facing during the take off;

wherein the UAV is configured to obtain a plurality of photographs of the cell site about the plurality of flights, wherein each of the plurality of photographs is associated with one or more location identifiers;

wherein a processing system is configured to define a three dimensional (3D) model of the cell site based on the associated with one or more location identifiers and one or more objects of interest in the plurality of photographs, wherein the 3D model further includes the zone indicator for future flights; and

wherein, subsequent to creation of the 3D model, the UAV is relaunched from the launch location based on the zone indicator in the launch orientation to obtain updated photographs and the 3D model is updated by the processing system with the updated photographs.

18. The cell site of claim **17**, wherein the UAV lands at the launch location in the launch orientation, one or more operations are performed on the UAV, and the UAV is relaunched from the launch location in the launch orientation to obtain additional photographs.

19. The cell site of claim **17**, wherein the one or more location identifiers comprise at least two location identifiers comprising Global Positioning Satellite (GPS) and GLObal NAvigation Satellite System (GLONASS).

20. The cell site of claim **17**, wherein the processing system provides a graphical user interface (GUI) of the 3D model, and the GUI is utilized to perform a cell site audit.

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