US 20170277187A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2017/0277187 A1**

Refai et al. (43) **Pub. Date: Sep. 28, 2017**

(54) **AERIAL THREE-DIMENSIONAL SCANNER**

(71) Applicant: **Optecks, LLC**, Bixby, OK (US)

(72) Inventors: **Hakki H. Refai**, Bixby, OK (US); **Badia Koudsi**, Bixby, OK (US)

(21) Appl. No.: **15/445,382**

(22) Filed: **Feb. 28, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/301,268, filed on Feb. 29, 2016, provisional application No. 62/384,386, filed on Sep. 7, 2016.

Publication Classification

(51) **Int. Cl.**

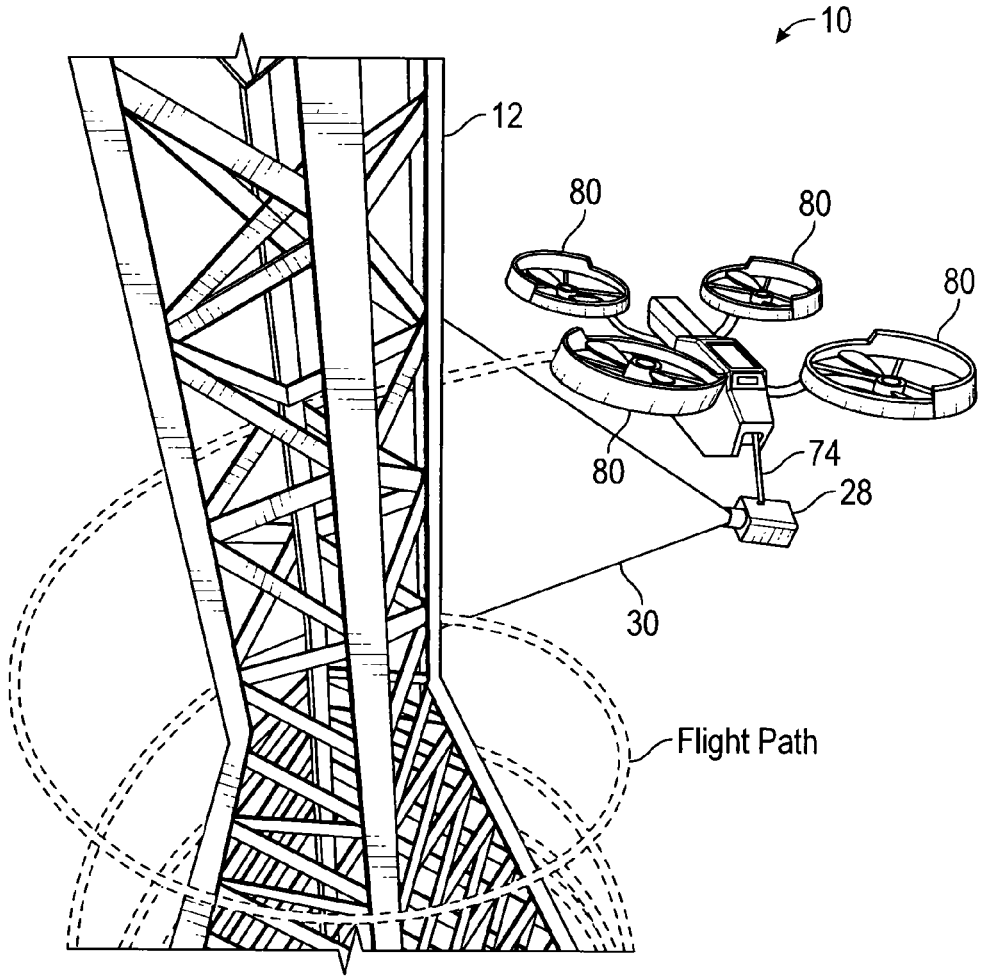
G05D 1/00	(2006.01)
H04N 7/18	(2006.01)
G05D 1/10	(2006.01)
G01S 17/89	(2006.01)
B64C 39/02	(2006.01)
B64D 47/08	(2006.01)
G06T 17/05	(2006.01)
G06T 7/30	(2006.01)

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

CPC ***G05D 1/0094*** (2013.01); ***G06T 17/05*** (2013.01); ***H04N 7/185*** (2013.01); ***G06T 7/30*** (2017.01); ***G01S 17/89*** (2013.01); ***B64C 39/024*** (2013.01); ***B64D 47/08*** (2013.01); ***G05D 1/101*** (2013.01); ***G05D 1/0088*** (2013.01); ***G05D 1/0011*** (2013.01); *B64C 2201/123* (2013.01); *B64C 2201/108* (2013.01)

(57) **ABSTRACT**

An aerial scanning system creates a model of a structure using an aerial platform configured to follow a flight path of movement about the structure and an optical scanner. A control system executes processing software reading data corresponding to at least one surface of the structure and, data corresponding to movement of the aerial platform about the structure, and uses the data to construct a three dimensional model of the structure.



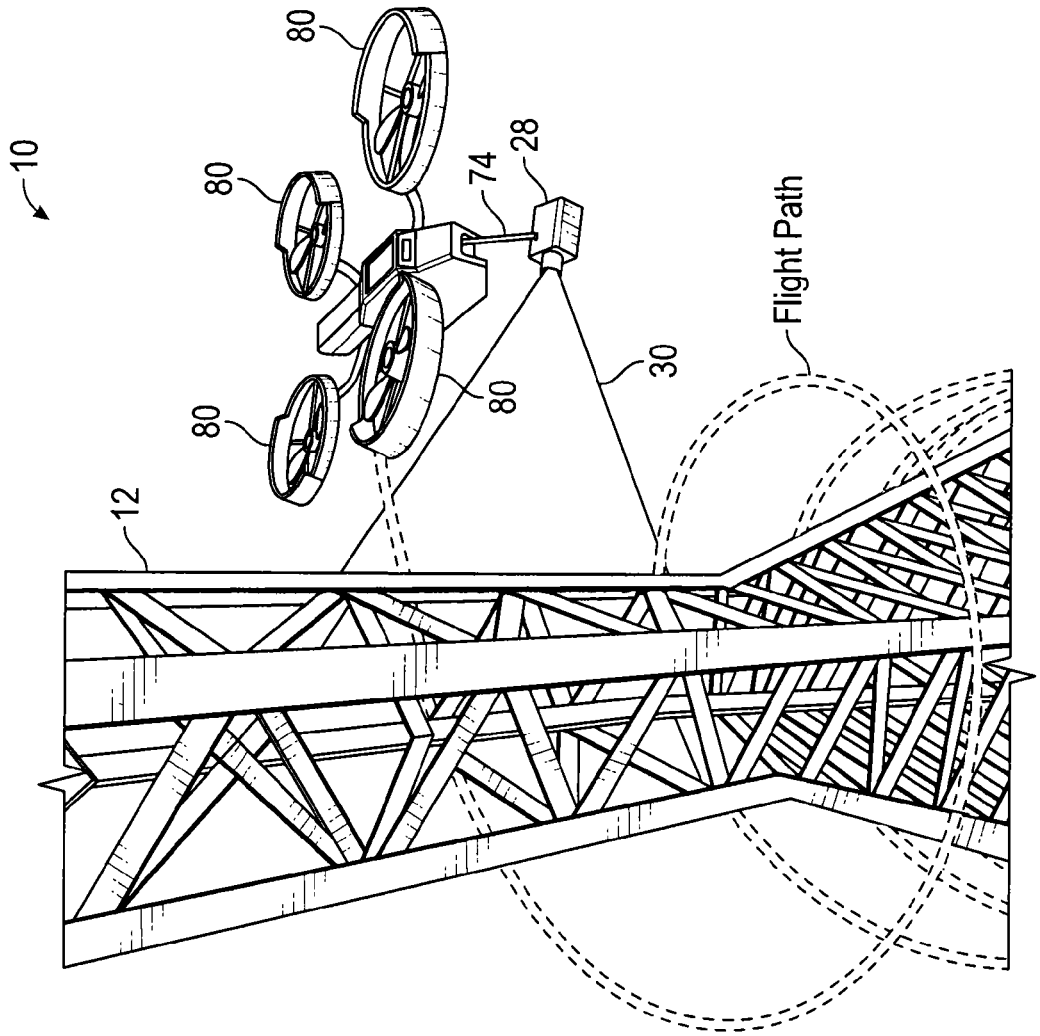


FIG. 1A

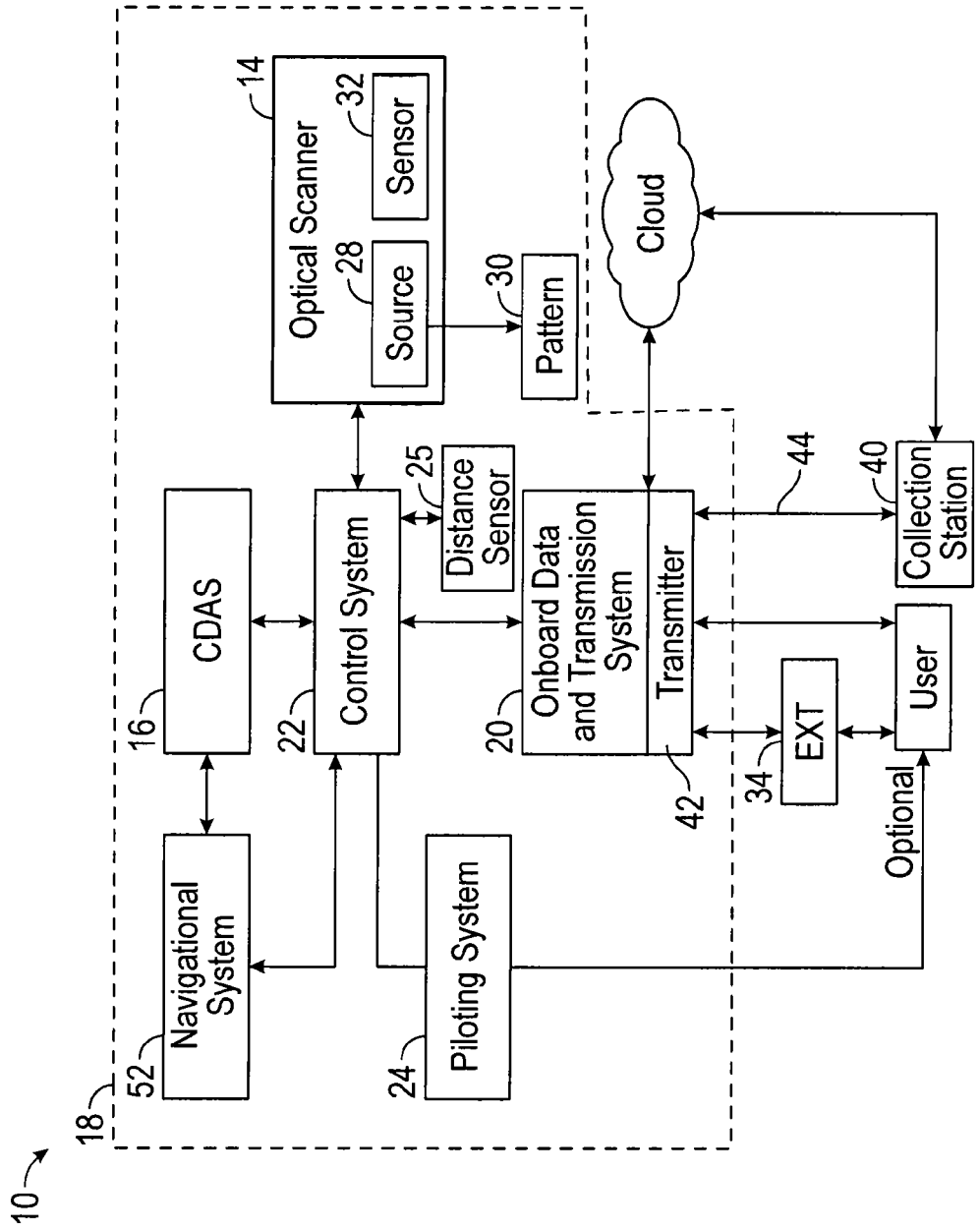

10
18
Optical Scanner
14
Sensor
32
Source
28
Pattern
30
Cloud
CDAS
16
Control System
22
Distance Sensor
25
Onboard Data and Transmission System
20
Transmitter
42
Collection Station
40
44
EXT
34
User
Optional
Navigational System
52
Piloting System
24

FIG. 1B

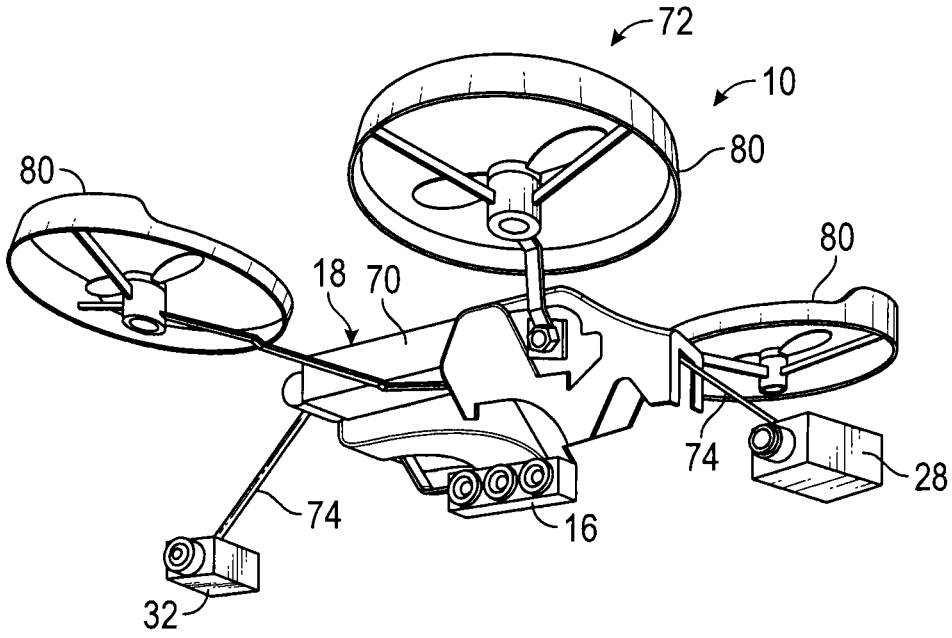


FIG. 2

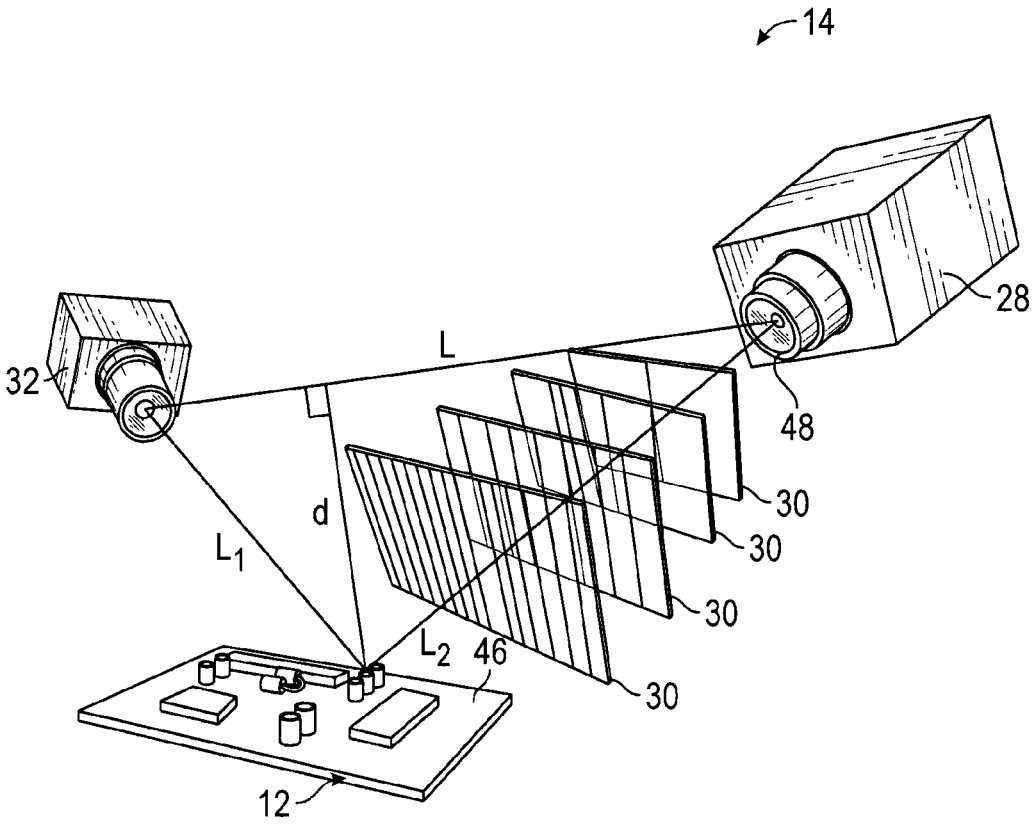


FIG. 3A

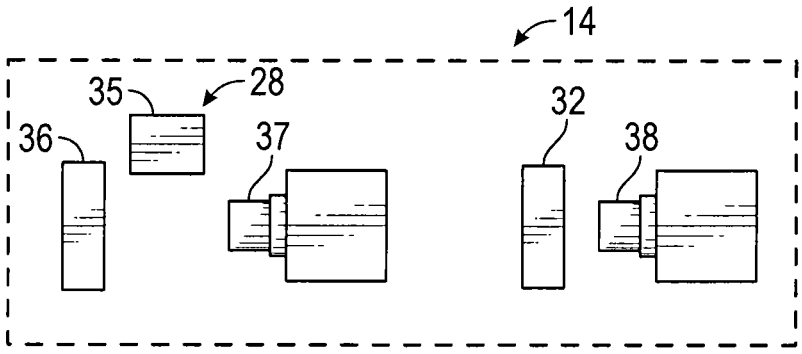


FIG. 3B

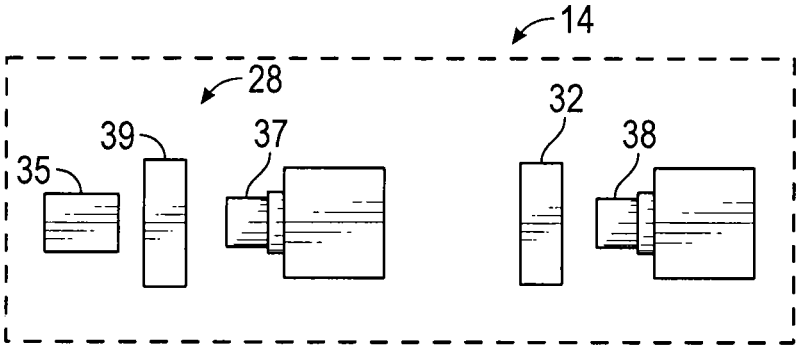


FIG. 3C

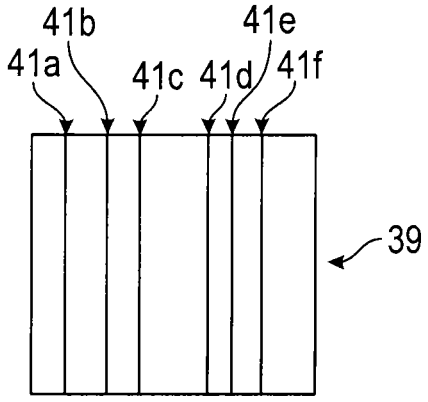


FIG. 3D

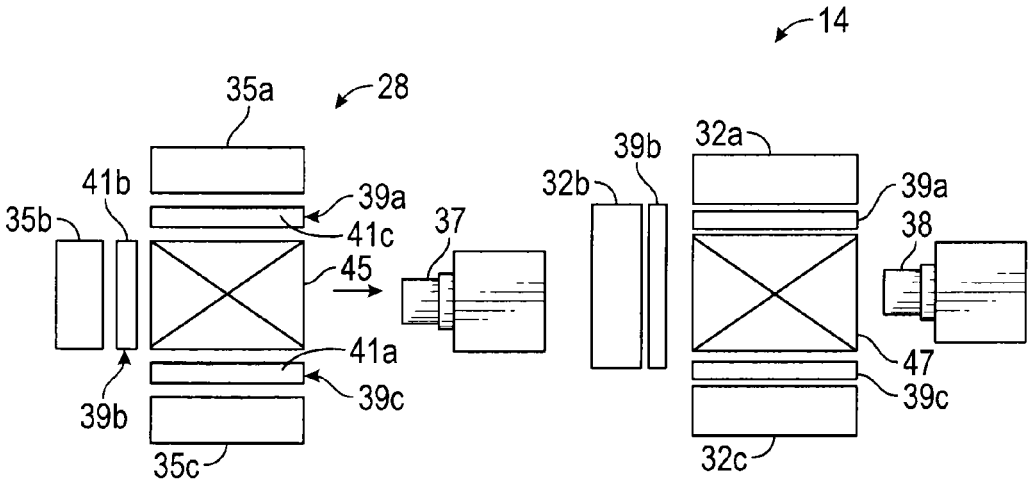

14
35a
28
41b
35b
39a
41c
37
45
41a
39b
39c
35c
39b
32a
32b
39a
38
47
39c
32c

FIG. 3E

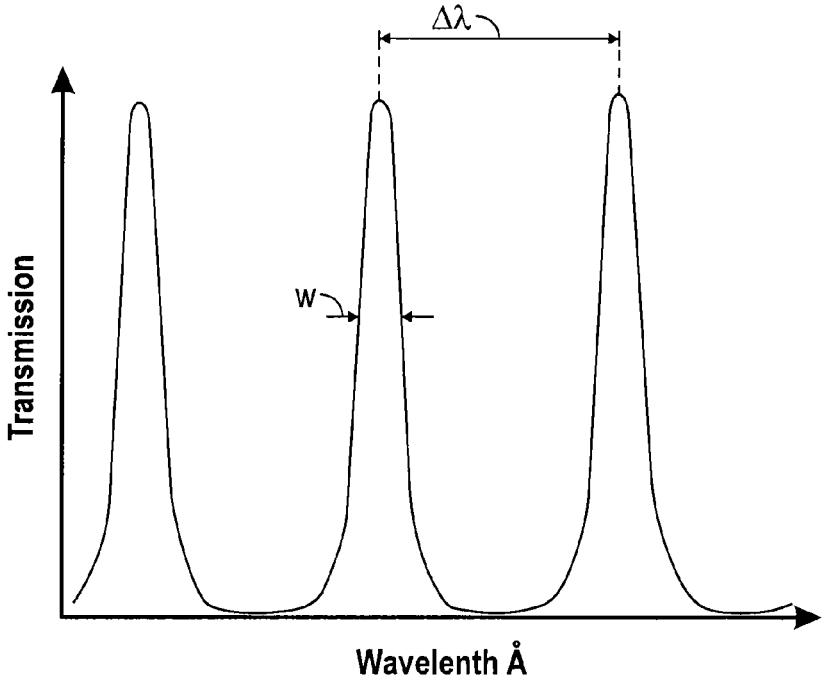

Δλ
w
Transmission
Wavelenth Å

FIG. 3F

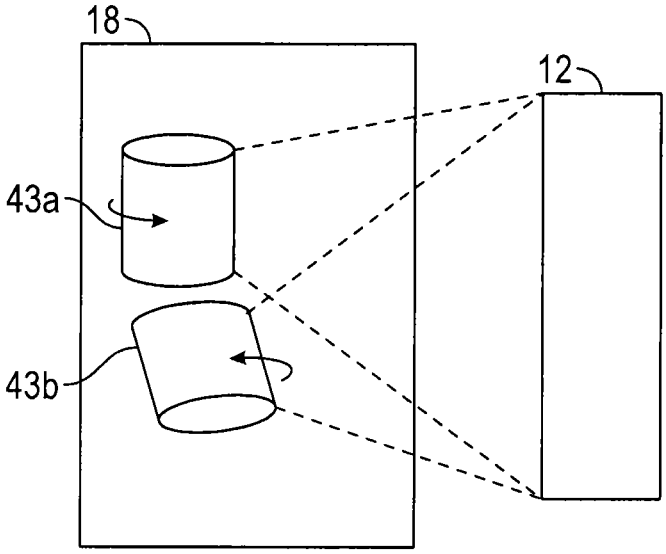

18
12
43a
43b

FIG. 3G

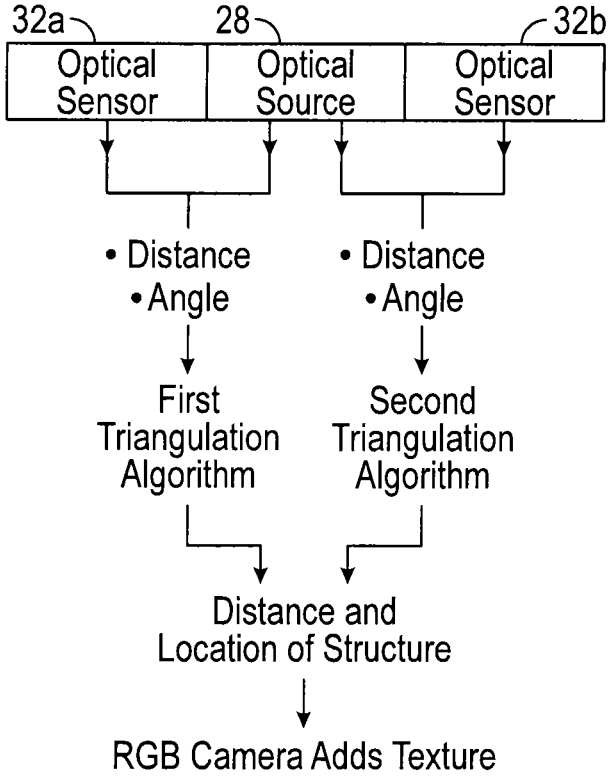

32a
28
32b
Optical Sensor
Optical Source
Optical Sensor
• Distance
• Angle
• Distance
• Angle
First Triangulation Algorithm
Second Triangulation Algorithm
Distance and Location of Structure
RGB Camera Adds Texture

FIG. 3H

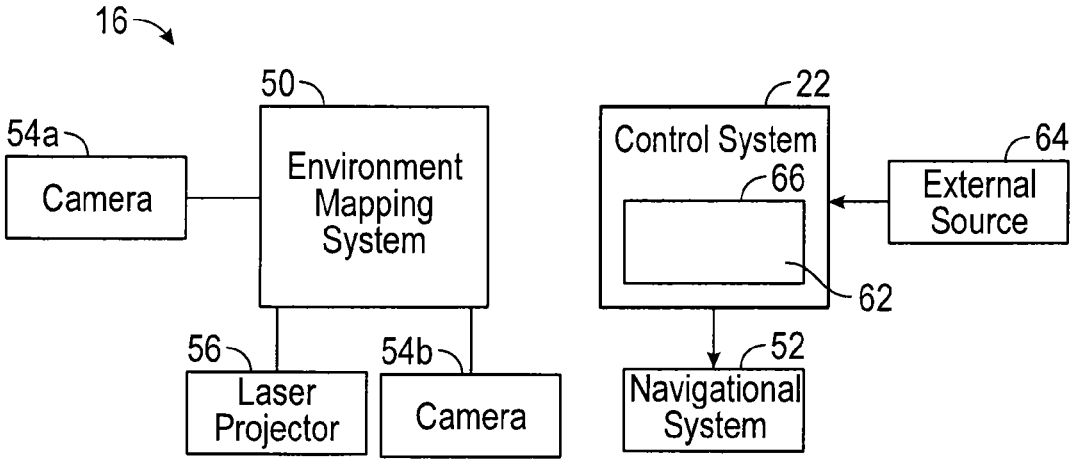


FIG. 4A

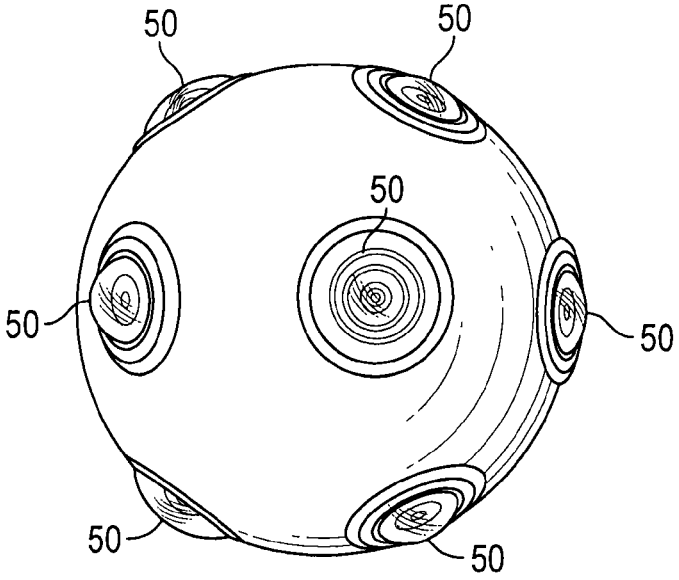


FIG. 4B

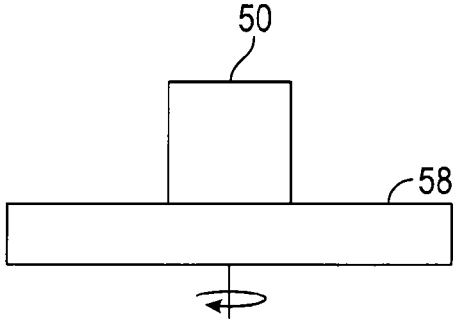


FIG. 4C

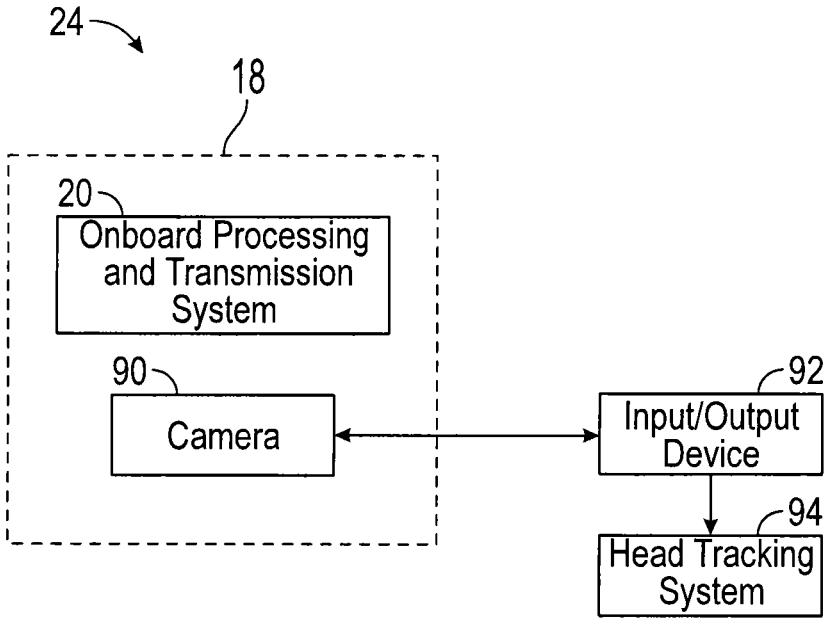


FIG. 5A

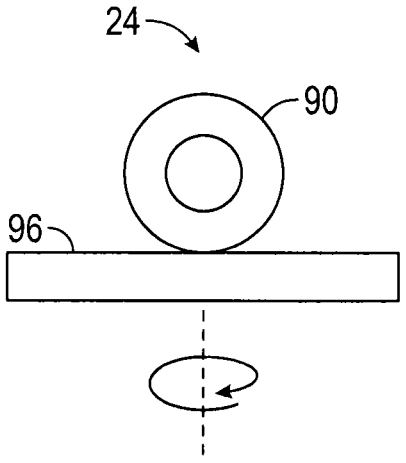


FIG. 5B

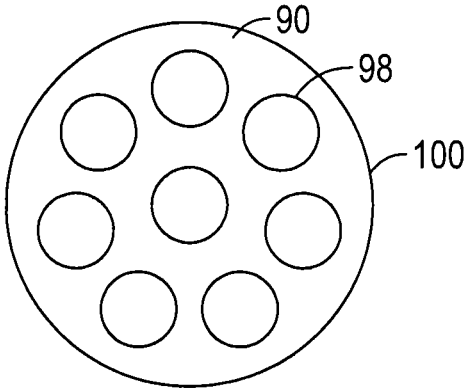


FIG. 5C

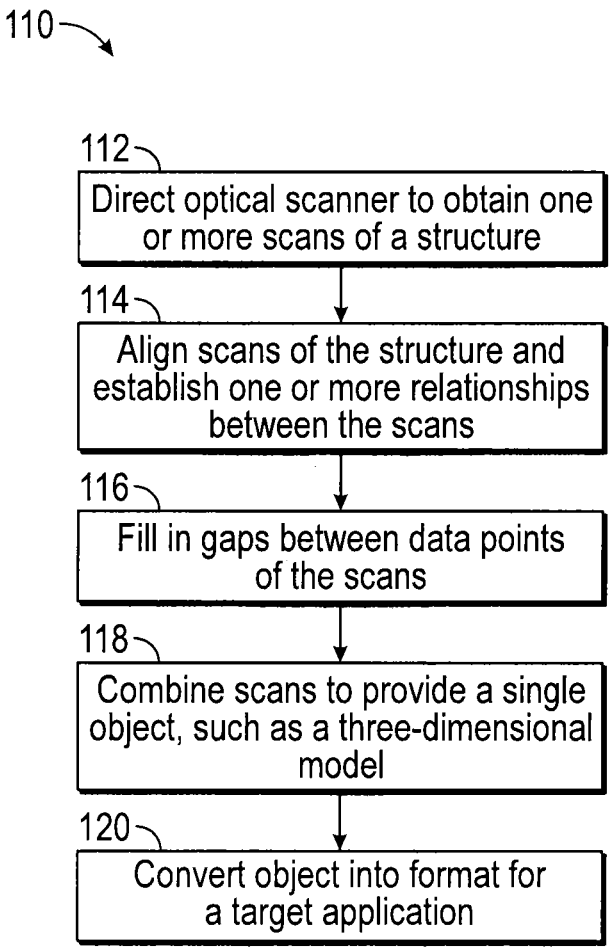

110
112
Direct optical scanner to obtain one or more scans of a structure
114
Align scans of the structure and establish one or more relationships between the scans
116
Fill in gaps between data points of the scans
118
Combine scans to provide a single object, such as a three-dimensional model
120
Convert object into format for a target application

FIG. 6

AERIAL THREE-DIMENSIONAL SCANNER

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] The present application claims the benefit of U.S. Ser. No. 62/301,268, filed Feb. 29, 2016, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Throughout the United States and the world, there exists many thousands to millions of large, infrastructure-critical structures that require inspection and possibly modification to maintain functional integrity. For example, broadcast and network towers, high-voltage transmission line towers, bridges, airplanes, and wind turbines are a few structures that may require regular inspection and/or maintenance. Such maintenance may be on a regular schedule, such as yearly, to ensure early detection of damage to the structure and/or structural components. Many structures may undergo modifications as the conditions under which they operate may change and/or evolve. Cellular towers, for example, may regularly receive new or upgraded antennas. In another example, electrical towers may receive new supports for additional cabling. Regular inspection and/or upgrading of such structures may ensure long term structural integrity and/or minimize susceptibility to damage or failure.

[0003] There are issues in performing inspections and/or maintenance on such structures. First, the size of such structures may be large and cumbersome. For example, cell towers may be up to 300 feet tall. Additionally, location of the structure may be remote or involve difficult terrain, such as deep gorges for bridges. Current methods in the prior art for carrying out inspections provides for inspectors to observe the structure or video the structure for review. Alternatively, long-distance, high power swept-laser scanners may be used. Each of these methods, however, may present significant issues or limitations.

[0004] Direct inspection by human technicians may present safety risks due to extreme heights and potential weather situations. Further, direct inspection by a human may suffer from limited measurement accuracy and may prove to be costly in both time and money needed to complete the scanning and/or subsequent modification processes. Using cranes or similar equipment may present issues with inspection speed and/or scheduling. For example, such equipment may move slowly and require time to stabilize prior to taking each measurement. This in turn may slow down the inspection process. For wind turbines, only 10 cranes suitable for performing the task even exist in the United States. This may further present scheduling issues, as well as the cost of moving the crane between sites.

[0005] The use of specialized laser scanners for performing inspection may also present issues. Such equipment is known to have limited accuracy and may also require a clear view of the entire structure from a distance. This may prove difficult for structures located in dense urban areas or in densely spaced groupings.

[0006] As such, a need exists for a scanning system that may provide safe, accurate and efficient methods for measurement and/or capture of large structures. Such measurement and/or capture of large structures may provide a cost effective method for inspection and aid in maintenance and/or repair of structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Several embodiments of the present disclosure are hereby illustrated in the appended drawings. It is to be noted however, that the appended drawings only illustrate several typical embodiments and are therefore not intended to be considered limiting of the scope of the present disclosure. Further, in the appended drawings, like or identical reference numerals or letters may be used to identify common or similar elements, and not all such elements may be so numbered. The figures are not necessarily to scale, and certain features and certain views of the figures may be shown as exaggerated in scale or in schematic in the interest of clarity and conciseness. Various dimensions shown in the figures are not limited to those shown therein and are only intended to be exemplary.

[0008] FIG. **1**A is a perspective view of an exemplary aerial scanning system of the present disclosure.

[0009] FIG. **1**B is a schematic diagram of the exemplary aerial three-dimensional scanning system illustrated in FIG. **1**A.

[0010] FIG. **2** is a perspective view of an exemplary aerial scanning system of the present disclosure having an optical scanner and a collision detection and avoidance system.

[0011] FIGS. **3**A-**3**E illustrate diagrammatic views of exemplary optical scanner systems for use in the aerial scanning system illustrated in FIG. **2**.

[0012] FIG. **3**F illustrates a graph of transmission range filters used within the optical scanner system of the present disclosure.

[0013] FIG. **3**G illustrates a diagrammatic view of another exemplary optical scanner system for use in the aerial scanning system illustrated in FIG. **2**.

[0014] FIG. **3**H illustrates a block diagram of an exemplary method of using an optical scanner system having multiple optical sensors and an optical source.

[0015] FIG. **4**A is a diagrammatic view of an exemplary collision detection and avoidance system for use in the aerial scanning system illustrated in FIG. **2**.

[0016] FIG. **4**B is a diagrammatic view of an exemplary environment mapping system for use in the collision detection and avoidance system of FIG. **4**A.

[0017] FIG. **4**C is a diagrammatic view of another exemplary environment mapping system for use in the collision detection and avoidance system of FIG. **4**A.

[0018] FIG. **5**A is a diagrammatic view of an exemplary piloting system for use in the aerial scanning system illustrated in FIG. **2**.

[0019] FIG. **5**B is a diagrammatic view of an exemplary camera system for use in the piloting system illustrated in FIG. **5**A.

[0020] FIG. **5**C is a diagrammatic view of another exemplary camera system for use in the piloting system illustrated in FIG. **5**A.

[0021] FIG. **6** is a flowchart of an exemplary method to provide one or more three-dimensional models of a structure using the aerial scanning system of the present disclosure.

DETAILED DESCRIPTION

[0022] The present disclosure describes an aerial three-dimensional scanning system providing a safe, accurate and efficient method for measurement and capture of structures. Generally, the aerial three-dimensional scanning system may include a scanning system coupled with data processing and reconstruction software, capable of producing three-dimensional maps (i.e., scans) of structures without endangering the operator, structures, or persons in the surrounding environment.

[0023] In some embodiments, the aerial three-dimensional scanning system may provide a method for measurement and capture of large structures (e.g., 200-500 feet), although structure of any height may be measured and/or captured. Generally, the aerial three-dimensional scanning system may achieve micrometer resolution and measurement accuracy below the minimum industry requirement of $1/16^{th}$ of an inch. In some embodiments, the aerial three-dimensional scanning system may fly autonomously about an object during a scan avoiding obstacles (e.g., support wires, structures, surrounding vegetation).

[0024] In some embodiments, an operator may be capable of utilizing augmented reality technology to monitor the scanning process, interrupt, and/or modify the scanning process.

[0025] In some embodiments, the aerial three-dimensional scanning system may output CAD files of the structure for upgrade, modification, and/or repair. Additionally, the aerial three-dimensional scanning system may provide one or more artificial intelligence (AI) responses regarding maintenance and/or inspection. For example, the three-dimensional scanning system may provide a response of yes/no or pass/fail for maintenance and inspection purposes, respectively.

[0026] Before describing various embodiments of the present disclosure in more detail by way of exemplary descriptions, examples, and results, it is to be understood that the embodiments of the present disclosure are not limited in application to the details of systems, methods, and compositions as set forth in the following description. The embodiments of the present disclosure are capable of other embodiments or of being practiced or carried out in various ways. As such, the language used herein is intended to be given the broadest possible scope and meaning; and the embodiments are meant to be exemplary, not exhaustive. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting unless otherwise indicated as so. Moreover, in the following detailed description, numerous specific details are set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to a person having ordinary skill in the art that the embodiments of the present disclosure may be practiced without these specific details. In other instances, features which are well known to persons of ordinary skill in the art have not been described in detail to avoid unnecessary complication of the description.

[0027] Unless otherwise defined herein, scientific and technical terms used in connection with the embodiments of the present disclosure shall have the meanings that are commonly understood by those having ordinary skill in the art. Further, unless otherwise required by context, singular terms shall include pluralities and plural terms shall include the singular.

[0028] All patents, published patent applications, and non-patent publications referenced in any portion of this application are herein expressly incorporated by reference in their entirety to the same extent as if each individual patent or publication was specifically and individually indicated to be incorporated by reference.

[0029] As utilized in accordance with the concepts of the present disclosure, the following terms, unless otherwise indicated, shall be understood to have the following meanings:

[0030] The use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one." The use of the term "or" in the claims and/or the specification is used to mean "and/or" unless explicitly indicated to refer to alternatives only or when the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and "and/or." The use of the term "at least one" will be understood to include one as well as any quantity more than one, including but not limited to 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 30, 40, 50, 100, or any integer inclusive therein. The term "at least one" may extend up to 100 or 1000 or more, depending on the term to which it is attached; in addition, the quantities of 100/1000 are not to be considered limiting, as higher limits may also produce satisfactory results. In addition, the use of the term "at least one of X, Y and Z" will be understood to include X alone, Y alone, and Z alone, as well as any combination of X, Y, and Z.

[0031] As used in this specification and claim(s), the words "comprising" (and any form of comprising, such as "comprise" and "comprises"), "having" (and any form of having, such as "have" and "has"), "including" (and any form of including, such as "includes" and "include") or "containing" (and any form of containing, such as "contains" and "contain") are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

[0032] The term "or combinations thereof" as used herein refers to all permutations and combinations of the listed items preceding the term. For example, "A, B, C, or combinations thereof" is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB. Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AAB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

[0033] Throughout this application, the term "about" is used to indicate that a value includes the inherent variation of error that exists among the study subjects. Further, in this detailed description, each numerical value (e.g., temperature or time) should be read once as modified by the term "about" (unless already expressly so modified), and then read again as not so modified unless otherwise indicated in context. Also, any range listed or described herein is intended to include, implicitly or explicitly, any number within the range, particularly all integers, including the end points, and is to be considered as having been so stated. For example, "a range from 1 to 10" is to be read as indicating each possible number, particularly integers, along the continuum between

about 1 and about 10. Thus, even if specific data points within the range, or even no data points within the range, are explicitly identified or specifically referred to, it is to be understood that any data points within the range are to be considered to have been specified, and that the inventors possessed knowledge of the entire range and the points within the range. Further, an embodiment having a feature characterized by the range does not have to be achieved for every value in the range, but can be achieved for just a subset of the range. For example, where a range covers units 1-10, the feature specified by the range could be achieved for only units 4-6 in a particular embodiment.

[0034] As used herein, the term "substantially" means that the subsequently described event or circumstance completely occurs or that the subsequently described event or circumstance occurs to a great extent or degree. For example, the term "substantially" means that the subsequently described event or circumstance occurs at least 90% of the time, or at least 95% of the time, or at least 98% of the time.

[0035] Referring to the Figures, and in particular to FIGS. **1**A and **1**B, illustrated therein is an aerial scanning system **10** for constructing one or more three-dimensional scans of one or more structures **12** in accordance with the present disclosure. Generally, the aerial scanning system **10** is configured to provide three-dimensional scans (e.g., maps) of structures without endangering the operator, the structure **12**, or persons in surrounding environments. For example, the structure **12** may be a utility tower having antennas, wire and other obstacles. The aerial scanning system **10** may follow a flight path about the structure **12** (e.g., rotate about the tower) at a relatively close distance avoiding obstacles such as the tower, antenna, wire, and/or the like. Additionally, the aerial scanning system **10** may be configured to output three dimensional or two dimensional files (e.g., CAD files) of the structure **12** for upgrade, modification and/or repair purposes.

[0036] In some embodiments, the aerial scanning system **10** may include one or more artificial intelligence (AI) responses (e.g., yes/no, pass/fail) for maintenance and/or inspection recommendation and/or action items. For example, the aerial scanning system **10** may scan the structure **12** (e.g., utility tower) with high accuracy. An AI analysis and inspection software may process a three-dimensional generated file (e.g., CAD file) to determine if there is a failure (e.g., bar, rode, and/or piece of the structure **12** having a bend and/or weak portion, loose screw, and/or the like). The AI analysis and inspection software may provide one or more communications (e.g., report) to a user indicating location of failure and/or one or more recommendation and/or action items (e.g., replace bar, tighten screw) related to the failure. The AI analysis and inspection software may also provide a "Pass Inspection" response if no failure is determined.

[0037] In some embodiments, the aerial scanning system **10** may comprise an optical scanner **14**, a collision detection and avoidance system **16**, an aerial platform **18**, onboard data processing and transmission system **20**, a control system **22**, and a piloting system **24**. In some embodiments, the aerial scanning system **10** may further include a distance sensor **25** configured to measure a distance between the aerial platform **18** and the structure **12**. The distance sensor **25** may measure the distance between the aerial platform **18** and the structure **12** when the aerial scanning system **10** is in use and/or for each scan obtained, for example. Generally, each element of the aerial scanning system **10** may be used in conjunction to construct one or more three-dimensional scans of the structure **12**. For example, using the piloting system **24**, a user may pilot the aerial platform **18** via virtual reality, augmented reality, smartphone (e.g., iPhone), tablet, joystick, remote control system, and/or the like. In some embodiments, the aerial scanning system **10** may be piloted autonomously (i.e., user direction may be optional). One or more cameras (e.g., stereoscopic camera, standard camera, 360 degree camera, combinations thereof, or the like) on the aerial platform **18** may present one or more views of the environment to the user. For example, the user may be provided one or more views of a natural environment for positioning and/or moving the aerial platform **18** around the structure **12**. The virtual or augmented reality may allow for the user to observe the structure **12** and/or the environment from the point of view of the aerial platform **18**, as if the user is on the aerial platform **18**. Additionally, virtual or augmented reality may provide the user additional information about flight and/or operating status of the aerial platform **18**. In some embodiments, the user may utilize a radio-frequency control module configured to transmit commands to the aerial platform **18** during flight of the aerial platform **18**. The nature of the commands may depend on flying and/or propulsion mechanism in use by the aerial platform **18**, including, but not limited to, multiple rotors (e.g., quad or octo-rotor), jet propulsion, or the like.

[0038] Once the aerial platform **18** is in flight, the optical scanner **14** may be used to gather data regarding the structure **12**. The optical scanner **14** may include an optical source **28** capable of projecting an optical pattern **30** on the structure. An optical sensor **32** of the optical scanner **14** may record data of the illumination (i.e., projection of the optical pattern **30**) on the structure **12**. The mounting of the optical source **28** and the optical sensor **32** on the aerial platform **18** may provide the rigidity to ensure that the optical source **28** and the optical sensor **32** remain in the same geometrical relationship (i.e., static geometrical relationship) with each other without significant movement during and/or between recording events. Additionally, such mounting may be lightweight to avoid consuming payload capacity of the aerial platform **18**.

[0039] The data obtained from the optical sensor **32** may be combined with knowledge of distance between the optical source **28** and the optical sensor **32**, angular orientation of the optical source **28** and the optical sensor **32**, and content of the optical pattern **30** to estimate the three-dimensional structure of the structure **12** using active triangulation algorithms. The distance between the optical source **28** and the optical sensor **32**, angular orientation of the optical source **28** and the optical sensor **32** can be fixed or dynamic. But, when the distance and the angular orientation are dynamic, then such may be known prior to utilization in the active triangulation algorithms. In some embodiments, the optical source **28** may illuminate the structure **12** with a single optical pattern **30** for each reading. To improve accuracy of the three-dimensional model, in some embodiments, the optical scanner **14** may illuminate the structure **12** with a series of optical patterns **30**. Each pattern in the series may provide additional data about the structure **12** to alter the three-dimensional model. During the illumination series,

the user may attempt to maintain the aerial platform at a stationary position (i.e., reducing movement between two patterns in series).

[0040] In some embodiments, an optional external optical system **34** may provide additional low resolution scans of the environment surrounding the aerial platform **18** from a ground position. An exemplary external optical system **34** may be the Intel RealSense technology, manufactured by Intel having a principal place of business in Santa Clara, Calif. Such scans may provide data on the environment surrounding the aerial platform **18** including, but not limited to, objects interfering with the flight path of the aerial platform **18** that an on-board camera may not be capable of viewing, the structure **12**, and/or the like. The user and/or the control system **22** may use such data to avoid collisions with the structure **12** and/or interfering objects that may damage, incapacitate and/or destroy the aerial platform **18**.

[0041] The control system **22** may generally coordinate the operation of the optical scanner **14**, the collision detection and avoidance system **16**, the onboard data processing and transmission system **20** and the distance sensor **25**. For example, for the optical scanner **14**, the control system **22** may determine the number of optical patterns **30** displayed per second, illumination time for each optical pattern **30**, and/or the time at which the optical scanner **14** may sample and/or store the output for further processing and/or transmission. The control system **22** may obtain input from the collision detection and avoidance system **16** and either alert the user when the aerial platform **18** may be at a predetermined distance to the structure **12** or interfering object, thus allowing the user to decide appropriate action. In some embodiments, the control system **22** may signal the aerial platform **18** to take rapid evasive action independent of the user.

[0042] In some embodiments, the onboard data processing and transmission system **20** may perform initial electronic processing in preparation for transmission to a collection station **40**. Such processing may include, but is not limited to, data compression, preliminary registration (e.g., compensation for movement of the aerial platform **18** between captures), encapsulation of data in a format used by a transmission link, and/or the like.

[0043] In some embodiments, a transmitter **42** (e.g., RF transmitter) of the onboard data processing and transmission system **20** may transmit the processed data to the collection station **40**. For example, the transmitter **42** may transmit the processed data to the collection station via a network **44** and/or cloud. Such network **44** may be implemented as the World Wide Web (or Internet), a local area network (LAN), a wide area network (WAN), a metropolitan network, a wireless network, a cellular network, a Global System for Mobile Communications (GSM) network, a code division multiple access (CDMS) network, a 3G network, a 4G network, a 5G network, a satellite network, a radio network, an optical network, a cable network, a public switched telephone network, an Ethernet network, combinations thereof, and/or the like. It is conceivable that in the near future, embodiments of the present disclosure may use more advanced networking topologies.

[0044] Location of the collection station **40** may include, but is not limited to, a vehicle, building, or other stationary object, or a second aerial vehicle (e.g., airplane). Within the collection station **40**, or within a second location in communication with the collection station **40**, a receiver may collect and/or retrieve the processed data sent by the transmitter **42**. The collection station **40** may include one or more processors having processing software configured to convert the processed data into three-dimensional models using registration, generalization and fusion processing cycles for constructing three-dimensional models. The one or more processors may format the three-dimensional model (e.g., SolidWorks file), and/or deliver the three-dimensional model to an end user.

[0045] Referring to FIGS. **2** and **3**A, the optical scanner **14** may include one or more optical sources **28** capable of projecting one or more optical patterns **30** onto the structure **12** and one or more optical sensors **32** capable of measuring spatial variation in intensity and/or color of the optical pattern **30** on the structure **12**. Generally, the one or more optical sources **28** and the one or more optical sensors **32** may be separated by a known and fixed lateral distance l as shown in FIG. **2**. Additionally, the one or more optical sources **28** and the one or more optical sensors **32** may be oriented at fixed angles to a line connecting the one or more optical sources **28** and the one or more optical sensors **32**.

[0046] The optical source **28** may be any light source capable of generating one or more optical patterns **30** (e.g., a high resolution 1920×1080 optical pattern). For example, the optical source **28** may include, but is not limited to, digital light processing (DLP), liquid crystal display (LCD), liquid crystal on silicone (LCoS), mask screens, arrays of light emitters (e.g., light-emitting diodes (LEDs)), and/or the like. The optical source **28** may be limited to single color systems (e.g., red, blue, green, infrared light, UV light, laser of these wavelengths) or multicolor systems (e.g., RGB, RG, GB, RB, combinations of infrared wavelengths, visible and infrared wavelengths, UV and possible combinations, or laser of these wavelengths).

[0047] The optical pattern **30** projected by the one or more optical sources **28** may be any color of light. For example, the optical pattern **30** may include a single color of light, different colors of light, gray scales of light, different color and different gray scales, and/or the like. Generally, the one or more optical patterns **30** may be selected such that data volume is produced that is sufficient for accurate reconstruction. Such optical patterns **30** may include, but are not limited to, a set of high resolution optical patterns, binary patterns, gray patterns, phase shift patterns, hybrid gray and phase shift patterns, rainbow patterns, continuously varying color patterns, color coded stripes, segmented stripes, gray scale coded stripes, De Bruijin Sequence, Pseudo Random Binary dots, mini-patterns as codewords, color coded grids, two dimensional coded dot array, and/or any combination thereof. Exemplary patterns and associated measurement techniques may be found in the article by Jason Geng, *Structured-light 3D Surface Imaging: a tutorial*, Advances in Optics and Photonics 3, 128-160 (2011), a copy of which is submitted herewith and is hereby incorporated by reference in its entirety.

[0048] During the scanning process, the optical source **28** may illuminate the structure **12** with one or more different images or frames (i.e., multi shots such as binary code, gray code, phase shift code, hybrid of gray code and phase shift code, other hybrids, and/or the like), or single image or frame (i.e., single shot such as color coded stripes, segmented stripes, gray scale coded stripes, De Bruijin sequence, pseudo random binary dots, mini-patterns as

codewords, color coded grid, two dimensional color coded dot array, hybrids, and/or the like).

[0049] Generally, illumination and/or the optical pattern (s) **30** may be executed according to a pre-determined protocol, such as the techniques defined in the article by Jason Geng cited herein and incorporated by reference in its entirety. Key parameters for selection of the appropriate protocol may include frame speed (number of images or frames the pattern generator may produce in full per unit time), resolution of the pattern generator (e.g., density and size of mirrors, liquid crystal cells, or light emitters in the array). For example, in some embodiments, the DMD may provide diversity of optical patterns **30** per unit of time and a large number of illumination points as compared to other methods for producing optical patterns **30**.

[0050] The optical sensor **32** may obtain data for each frame for multi shots and a single frame for a single shot. The determination of multi shot or single shot may be based on avoidance in errors for reconstruction, decrease software complexity and/or increased accuracy. Errors, for example, may arise when a portion of an object obstructs and/or shadows the structure **12**. In this example, optical patterns **30** may have illuminated areas and non-illuminated areas with each area being able to reveal details of the structure **12**.

[0051] In some embodiments, the optical source **28** may sequentially illuminate the structure **12** with optical patterns **30** of different colors. Such sequential illumination may reduce and/or eliminate loss of accuracy that may occur when the structure **12** and the optical source **28** have similar colors.

[0052] Referring to FIG. **3**B, in some embodiments, the optical source **28** may be a DLP source having an illumination module **35**, a digital micromirror device (DMD) **36**, and a projection lens **37**. The illumination module **35** may deliver optical power at one or more multiple wavelengths to the DMD **36**. The DMD **36** may include one or more arrays of electro-mechanical mirrors. The pattern of activated and deactivated mirrors may modulate the incoming illumination providing a pattern of illumination at the output plane. The projection lens **37** may produce a clear image of the optical pattern **30** or code at a designed distance. The projection lens **37** may include, but is not limited to, one or more liquid lens, dynamic lens, variable lens, mechanical lens, tunable lens, electroactive polymer lens, and/or the like. In some embodiments, the projection lens **37** may be a tunable lens configured to later focus based on one or more communications from the control system **22**. For example, the control system **22** may alter the focus of the tunable lens based on a measured distance between the aerial platform **18** and the structure **12**. Exemplary tunable lens may be manufactured by Optotune having a principal place of business in Switzerland or Varioptic having a principal place of business in Lyons, France. In using a tunable lens, for example, the distance between the aerial platform **18** and the structure **12** may be different each time the optical scanner **14** operates. To that end, tuning of the optical scanner **14** may be automatic (i.e., distance may be varied and not fixed each time the optical scanner **14** operates). It should be noted that the LDC, LCoS, mark screen and light-emitter array may also produce patterns of illumination, though by means one skilled in the art will appreciate.

[0053] Additionally, in some embodiments, the optical sensor **32** may be used in conjunction with one or more camera lens **38** as shown in FIG. **3**B. Similar to the projection lens **37**, the camera lens **38** may include, but is not limited to, one or more liquid lens, dynamic lens, variable lens, mechanical lens, tunable lens, electroactive polymer lens, and/or the like. Further, the control system **22** may be configured to alter the focus of the camera lens **38** automatically (i.e., without human intervention). For example, the control system **22** may be configured to alter the focus of the camera lens **38** using the measured distance between the aerial platform **18** and the structure **12** obtained via the distance sensor **25** (shown in FIG. **1**B). In some embodiments, the projection lens **37** may be a tunable lens configured to later focus based on one or more communications from the control system **22**. After the focal lengths of the projection lens **37** and/or the camera lens **38** are adjusted (e.g., adjusted automatically via the control system **22**), the focal lengths of the projection lens **27** and the camera lens **38** will be known. In some embodiments, the focal length f of the projection lens may be equal to the focal length f of the camera lens **38**.

[0054] Referring to FIGS. **1**B and **3**B, in some embodiments, the aerial platform **18** may further include one or more distance sensors **25** (e.g., ultrasonic sensor, optical time of flight sensors (e.g., laser), triangulation sensor, and/or the like) configured to measure the distance between the aerial platform **18** and the structure **12** prior to scanning. The measured distance between the aerial platform **18** and the structure **12** may additionally be used to tune the projection lens **37** and/or the camera lens **38** to project and/or capture clear and/or substantially clear patterns and/or images. The control system **22** may automatically (i.e., without human intervention) alter the projection lens **37** and/or the camera lens **38** using measured distance obtained from the distance sensor(s) **25**.

[0055] In some embodiments, the projection lens **37** and/or the camera lens **38** may include shutters (e.g., (f/16), (f/8), (f/2-8)). When the aperture of the shutter is in an open position (f/2-8) the projection lens **37** and/or the camera lens **38** may focus on a plane at a specific location. The aerial platform **18**, as such, may fly and/or hover at a specific distance based on the focal length f of the lens (projection lens **37** and/or camera lens **38**) to scan that portion of the structure **12** and receive a clear scan. When the aperture of the shutter is small (e.g., (f/16), (f/8)), the projection lens **37** and/or the camera lens **38** may focus over a specific depth (e.g., +/−10 cm), thus allow for the optical scanner **14** to operate and scan at a variable distance. It should be noted that reducing the aperture may affect brightness of the projected optical patterns **30** and captured images.

[0056] FIGS. **3**C and **3**D illustrate another exemplary embodiment of the optical scanner **14** wherein the optical source **28** includes one or more masks **39**. In some embodiments, the mask **39** may include two or more layers positioned adjacent to one another. For example, a first layer may include a first pattern. A second layer may include one or more filters **41** for each individual pixel (e.g., magenta **41***a*, cyan **41***b*, yellow **41***c*, green **41***d*, blue **41***e*, red **41***f* filters) aligned adjacent (e.g., directly on top of) the patterns to produce a colored pattern without the need for DLP or DMD optical source. Generally, in this example, the optical sensor **32** may include a color sensor (e.g., IR, UV, combination thereof, and/or the like).

[0057] FIG. **3**E illustrates another exemplary embodiment of the optical scanner **14** wherein the optical source **28** includes a plurality of illumination sources **35***a*, **35***b*, and

35*d* and a plurality of masks **39***a*, **39***b* and **39***d*. Filters **41** within the masks **39***a*, **39***b*, and **39***d* may be any colors (e.g., magenta **41***a*, cyan **41**, yellow **41***c*, green **41***d*, blue **41***e*, red **41***f*, IR, UV, or combinations thereof). In some embodiments, each filter **41** may be configured to pass one or more specific colors (e.g., pass two or more colors to increase differentiation and/or accuracy). A combiner **45** may combine all patterns from each of the filters **41** and deliver to the projection lens **37**. Further, the optical scanner **14** may include multiple optical sensors **32***a*, **32***b* and **32***c*, for example. Each optical sensor **32***a*, **32***b* and **32***c* may include one or more masks **39***a*, **39***b* and **39***c*, for example. The masks **39***a*, **39***b* and **39***c* allow transmission of specific wavelengths and rejection of specific wavelengths. A combiner **47** may distribute the received images from the camera lens **38** to the three sides. To that end, the optical source **28** may project three single shots and the optical sensor **32** may receive three single shots at any instance and may increase accuracy.

[0058] Referring to FIG. **3**F, in some embodiments, filters **41** used at the optical source **28** may be designed in respect to filters **41** used at the optical sensor **32**. For example, filters **41***b* of the optical source **28** may allow for projection of three colors R, G and B based on pixel distribution, and filters **41***b* of the optical sensor **32** may allow for images that include only R, G and B colors to pass through while reflecting the rest of the wavelengths. In some embodiments, the filters **41** may be Fabry Perot filters. For example, filter **41***b* may be configured to transmit images of R, G, and B colors while filter **41***c* may transmit images of CYM. In some embodiments, one or more bandpass filters may be used as filters **41** to provide transmission of different ranges and/or spectrums of wavelengths at each side of the combiner **45** (e.g., prism).

[0059] The optical sensor **32** may provide spatial resolution in measuring the object under illumination by the optical source **28**. The design of the optical sensor **32** may include, but is not limited to, a high-density detector array (e.g., high density charge-couple device (CCD) array), CMOS, array of photo-detection elements coupled to a high quality imaging lens, or the like. Exemplary resolutions may include, but are not limited to for 8K resolution of 7,680×4,320, for 4K (UHD) resolution of 3,840×2,160, for WUXGA resolution of 1,920×1,200, for 1080p resolution of 1,920×1,080, for XGA resolution of 1,024×768. The optical source **28** may operate at a wavelength detectable by the optical sensor **32**. In some embodiments, the optical source **28** may deliver optical power to the structure **12** such that the optical sensor **32** and the subsequent processing electronics may accurately record the projected optical pattern **30** even in the presence of high brightness ambient lighting conditions (e.g., bright sunlight). Alternatively, the scanning process may be scheduled for a time at which high brightness ambient lighting conditions are minimized. For example, in using the autonomous piloting system **24** described in further detail herein, the scanning process may be scheduled during night-time or dark lighting conditions.

[0060] In some embodiments, one or more additional cameras may be included within the optical scanner **14** to provide color and/or texture for the three-dimensional model. For example, one or more RGB cameras may be included within the optical scanner **14**. Subsequent to scanning of the structure **12**, the one or more additional cameras may capture one or more additional images. Such images may be used to add color and/or texture to the data obtained by the optical sensor **32**. During processing, such color and texture data may be applied to the three-dimensional model.

[0061] Referring to FIG. **3**F, n some embodiments, the optical scanner **14** may include a Light Detection and Ranging (LiDAR) system **43**. Generally, the LiDAR system **43** may measure distance to the structure **12** based on known speed of light and measurement of the time-of-flight of a light signal between the light or laser source and camera at one end (e.g., positioned on the aerial platform **18**) and the structure **12** for each point of the image. Each LiDAR system **43** may include optical transmitters (e.g., **64** optical transmitters) and optical receivers (e.g., **64** optical receivers) aligned on a single rotating column, for example. The time-of-flight camera is a class of scanner wherein an entire scene may be captured with each laser or light pulse, as opposed to a point-by-point capture used in scanning LiDAR systems **43**. An exemplary LiDAR system **43** for use in the optical scanner **14** may include the Velodyne LiDAR, manufactured by Velodyne having a principal place of business in Morgan Hill, Calif. In this example, the horizontal resolution may be higher than the vertical resolution. For example, the Velodyne has a horizontal resolution of 0.08 degrees and a vertical resolution of 0.4 degrees. In some embodiments, a single LiDAR system **43** may be included in the optical scanner **14** with horizontal resolution scanning horizontally.

[0062] In some embodiments, multiple LiDAR systems **43** may be included within the optical scanner **14**. For example, as illustrated in FIG. **3**G, two LiDAR systems **43***a* and **43***b* may be included within the optical scanner **14** with an angle between each system (e.g., 90 degrees) to capture horizontal resolution from each LIDAR system and scan both axes with high resolution scanning data. In this example, the resolution captured vertically and horizontally may be at 0.08 when using two Velodyne systems.

[0063] In some embodiments, the optical scanner **14** may include any combination of optical sources **28**, optical sensors **32** and/or LIDAR systems **43**. For example, the optical scanner **14** may include a LIDAR system with DLP structured light scanner, RGB camera with structured light system, RGB with structured light system and LIDAR system, RGB with structured light system and two LIDAR systems mounted perpendicular to each other, and/or the like.

[0064] The optical scanner **14** may operate on the principle of active triangulation. In some embodiments, computations may be determined by the control system **22**, the onboard processing system **20** and/or the collection station **40**. In some embodiments, computations may be determined by the control system **22** and/or the onboard processing system **20** and stored in one or more memory. The memory may then be transported and/or transmitted to the collection station **40** (e.g., via network, upon landing of the aerial platform **18** and/or the like.)

[0065] FIG. **3**A depicts the relative positioning and orientation of the optical source **28** and the optical sensor **32**. Known parameters may include the distance l between the optical source **28** and the optical sensor **32** and the angles of the optical source **28** and the optical sensor **32** with respect to a line connecting them. The optical sensor **32** may detect a point projected onto the structure **12**. The position of the point on a surface **46** of the structure **12** detected by the optical sensor **32** may provide for determination of the line

l_1 between the spot and a surface **48** of the optical sensor **32** (e.g., center of the surface **48** of the optical sensor **32**). The line l_1 may be determined using knowledge of the location and angle of the optical sensor **32**. A triangulation algorithm may then determine the location of point on the detecting surface **46**, by determining the intersection of lines l_1 and l_2.

[0066] An exemplary triangulation algorithm is shown below. Generally, the point (x, y, z) on the structure **12** and the location of its image on the optical sensor (x*, y*) relate to each other through the perspective transformations:

$$(T_{11}-T_{14}x^*)x+(T_{21}-T_{24}x^*)y+(T_{31}-T_{34}x^*)z+(T_{41}-x^*)=0, \quad \text{(EQ. 1)}$$

$$(T_{12}-T_{14}y^*)x+(T_{22}-T_{24}y^*)y+(T_{32}-T_{34}y^*)z+(T_{42}-y^*)=0, \quad \text{(EQ. 2)}$$

wherein T defines the scene to image transformation matrix determined for a given position and angle of the optical sensor **32**. Similarly, the optical source **28** located at (u, w) may have a perspective transformation:

$$(L_{11}-L_{14}u)x+(L_{21}-L_{24}u)y+(L_{31}-L_{34}u)z+(L_{41}-u)=0, \quad \text{(EQ. 3)}$$

$$(L_{12}-L_{14}w)x+(L_{22}-L_{24}w)y+(L_{32}-L_{34}w)z+(L_{42}-w)=0, \quad \text{(EQ. 4)}$$

wherein L defines the scene to source transformation matrix for a given position and angle of the optical source **28**. Both T and L depend on the system geometry in FIG. **2**. If the optical source **28** projects the structured optical pattern **30** onto the detection surface **46**, solving the four equations may produce an estimate of each coordinate triplet (x, y, z) within the optical pattern **30**, as the equations may be inconsistent due to error sources. The computation may arrive at a best estimate of coordinates by a least squares approach.

[0067] In some embodiments, resolution and/or accuracy may be achieved by selection of particular components and/or use of one or more reconstruction algorithms. Such parameters may include, but are not limited to, the separation distance l, the working distance d, maximum area of the structure **12** illuminated by the optical source **28**, sensor resolution, DMD resolution, LCD resolution, emitter array or similar device used to generate the optical patterns **30**, range of magnifications produced by the projection optics of the optical source **28**, and/or the like. For example, the DLP4710 DMD, manufactured by Texas Instruments having a principal place of business in Dallas, Tex., has an orthogonal 1920×1080 array of mirrors on a 5.4 μm pitch with a 0.47 inch diagonal. The selection of the particular DMD is not limited to this example, however, the selection of DMD may consider the DMD size and method of illumination (side illumination vs. corner illumination), as small DMD size and use of side illumination may reduce size and weight of the optical components, thereby reducing the size and weight of the optical source **28**. Common projection optics may produce a 1.3×0.8 m illuminated area at about 1.8 m, which may serve as a minimum working distance d to ensure safe flight of the aerial platform **18** around the structure **12** undergoing scanning. In some embodiments, the distance l may be minimized to achieve a target resolution such that the optical scanner **14** may not impact flying dynamics or payload capacity of the aerial platform **18**. A target accuracy for expected commercial application may be less than or equal to $\frac{1}{16}^{th}$ inch. Generally, a longer working distance may include a longer distance l to obtain the same accuracy, and the aerial scanning system **10** may balance working distance d and distance l for a given application.

[0068] In some embodiments, multiple optical sensors **32** may be used with the optical source **28** in the optical scanner **14**. For example, in FIG. **3**H, the distance and angle between the first optical sensor **32***a* and the optical scanner **14** may be determined and/or known. The distance and angle between the second optical sensor **32***b* and the optical scanner **14** may be determined and/or known. A first triangulation algorithm may be performed for the first optical sensor **32***a* and the optical source **28** and a second triangulation algorithm may be performed for the second optical sensor **32***b* and the optical source **28**. Using the results of the first triangulation algorithm and the second triangulation algorithm, the location of the point on the structure **12** may be determined and accuracy of such determination may be increased as compared to use of a single triangulation algorithm. Additionally, one or more additional cameras (e.g., RGB camera) may be configured to provide texture and/or additional data as described in further detail herein.

[0069] Referring to FIGS. **4**A-**4**C, the collision detection and avoidance system (CDAS) **16** may include an environment mapping system **50** and one or more navigational systems **52**.

[0070] In some embodiments, the environment mapping system **50** may provide insufficient resolution to perform high-accuracy measurements of the structure **12**; however, the environment mapping system **50** may provide sufficient three-dimensional renderings of the environment about the structure **12** for identification of obstacles in the flight path, proximity of the aerial platform **18** to the structure **12**, and/or the like. The environment mapping system **50** may additionally create real-time digital three-dimensional representations of the environment.

[0071] In some embodiments, the environment mapping system **50** may include two or more cameras **54** (e.g., RGB camera, IR camera) and/or one or more illumination sources **56** (e.g., laser projector). In some embodiments, a single wavelength specific pattern may be used in lieu of or in addition to the one or more illumination sources **56**. An exemplary environment mapping system **50** is RealSense system, manufactured by Intel having a principal place of business in Santa Clara, Calif.

[0072] In some embodiments, the environment mapping system **50** may include one or more RGB cameras **54***a*, one or more IR cameras **54***b*, and one or more laser projectors as the illumination source as shown in FIG. **4**A. The IR camera(s) **54***b* of the environment mapping system **50** may provide one or more stereoscopic recordings. Such stereoscopic recording may be used to determine depth data of the environment. By combining such stereoscopic readings with the data obtained by use of the one or more illumination sources **56**, the environment mapping system **50** may be able to provide a three-dimensional capture of the physical world. For example, the environment mapping system **50** may be configured to build a real-time digital representation of the three-dimensional scene and also provide data on distance to objects within the field of view. Even further, by using multiple environment mapping systems **50**, the CDAS system **16** may be capable of detection of objects over a larger field of view (e.g., 120 degrees) depending on placement and/or angular orientation of each environment mapping system **50**.

[0073] Generally, the environment mapping system **50** may provide full three-dimensional imaging and information regarding the environment in which the aerial platform

18 may operate. In some embodiments, multiple environment mapping systems 50 may be positioned in a spherical geometry such that each environment mapping system 50 may be oriented with its central axis directing outward from an effective or real surface of the sphere as illustrated in FIG. 4B. Referring to FIG. 4C, in some embodiments, one environment mapping system 50 may be positioned on a platform 58. The platform 58 may rotate independently of the aerial platform 18 and the optical scanner 14 such that the CDAS system 16 may be configured to scan the surrounding environment in a manner similar to a swept radar antenna (e.g., rotational movement for 360 degree horizontal mapping).

[0074] The control system 22 may receive data from the environment mapping system 50 and identify one or more objects of interest (e.g., objects of concern that may impede flight of the aerial platform 18). The control system 22 may use any computational algorithm existing for identification of objects of interest in three-dimensional mappings of physical environments. Generally, the control system 22 may include one or more processors 60 configured to automatically execute this methodology to identify and/or obtain information about objects of interest for a variety of purposes. In some embodiments, control system 22 may be configured to generate one or more reports for one or more objects of interest without manual or human intervention. For example, the methodology may be automatically executed by the one or more processors 60 to generate GPS coordinates, Cartesian map coordinates, simple distance and direction data, and/or the like. Such data may be used within the navigational system 52 to operate the aerial platform 18 and/or provided to a user for remote piloting of the aerial platform 18, for example. The control system 22 may format, configure and/or transmit the data to match ports (e.g., input/output ports) and protocols of receiving systems, including the user.

[0075] The control system 22 may include the one or more processors 60. In some embodiments, the processor 60 may be partially or completely network-based or cloud-based. The processor 60 may or may not be located in a single physical location. Additionally, multiple processors 60 may or may not be necessarily be located in a single physical location.

[0076] The processor(s) 60 may include, but are not limited to, implementation as a variety of different types of systems, such as a digital signal processor (DSP), a central processing unit (CPU), a field programmable gate array (FPGA), a microprocessor, a multi-core processor, a quantum processor, application-specific integrated circuit (ASIC), a graphics processing unit (GPU), a visual processing unit (VPU), combinations thereof, and/or the like.

[0077] The processor 60 may be capable of reading and/or executing executable code stored in one or more non-transitory processor readable medium 62 and/or of creating, manipulating, altering, and/or storing computer data structures into the one or more non-transitory processor readable medium 62. The non-transitory processor readable medium 62 may be implemented as any type of memory, such as random access memory (RAM), a CD-ROM, a hard drive, a solid state drive, a flash drive, a memory card, a DVD-ROM, a floppy disk, an optical drive, and combinations thereof, for example. The non-transitory readable medium 62 may be located in the same physical location as the processor 60, or located remotely from the processor 60 and may communicate via a network. The physical location of the non-transitory processor readable medium 62 may be varied, and may be implemented as a "cloud memory", i.e., one or more non-transitory processor readable medium 62 may be partially, or completely based on or accessed via a network.

[0078] In some embodiments, the control system 22 may configured to receive additional data from one or more external sources 64. In some embodiments, the external source 64 may be user inputted data. In some embodiments, the external source 64 may be data associated with a third party system (e.g., weather, GPS satellite). The information may be provided via a network or input device, including, but not limited to, a keyboard, touchscreen, mouse, trackball, microphone, fingerprint reader, infrared port, slide-out keyboard, flip-out keyboard, call phone, PDA, video game controller, remote control, fax machine, network interface, speech recognition, gesture recognition, eye tracking, brain-computer interface, combinations thereof, and/or the like.

[0079] In some embodiments, prior to movement of the aerial platform 18, a user may provide the control system 22 with some or all parameters to aid the CDAS system 16 in navigation. Parameters may include, but are not limited to, shape of structure 12, type of structure 12, suggested flight path, estimated height of structure 12, ground diameter of structure 12. The CDAS system 16 may include AI software configured to navigate the aerial platform 18 based on parameters, received data from environment mapping, extracted data from scanning data processed onboard or provided via network from a user, and/or the like.

[0080] Referring to FIG. 1-2, the aerial platform 18 may be configured to support and move the optical scanner 14, CDAS 16, onboard processing and transmission system 20, control system 22, and piloting system 24 within the air. Generally, the aerial platform 18 may be configured to move at a predetermined low speed (e.g., 1 km/h). Additionally, the aerial platform 18 may be configured to hover (i.e., remain stationary) within the air. For example, the aerial platform 18 may be configured to move at a low speed or hover as the optical scanner 14 obtains one or more scans of one or more areas of the structure 12. The aerial platform 18 may also include load capacity permitting unimpeded aerial navigation while transporting the optical scanner 14 and CDAS 16. Further, the aerial platform 18 may be configured to carry fuel to sustain long periods of flight (e.g., 2 hours) prior to refuelling to minimize time to complete a scanning process for the structure 12.

[0081] Generally, the aerial platform 18 may include one or more mechanical platforms 70, one or more propulsion systems 72, and one or more mounting systems 74. The navigational system 52 may aid in providing direction to the one or more propulsion systems 72.

[0082] In some embodiments, the propulsion system 72 may include four or more rotors 80 (e.g., quadcopter, octocopter), such as a drone. In some embodiments, the four or more rotors 80 may be electric-powered rotors. In some embodiments, relative rotational velocity of the four or more rotors 80 may be configured to control direction and/or speed of flight of the aerial platform 18. By controlling the relative rotational velocity of the four or more rotors 80, the aerial platform 18 may obtain slow and/or stationary flight (i.e., hovering), and may operate for extended periods of time. The aerial platform 18 may include other configura-

tions of the propulsion system **72** configured to utilize different placement and/or propulsion providing slow and/or stationary flight.

[0083] In some embodiments, the aerial platform **18** may include one or more power sources (not shown). The power sources may include one or more supplies of power to at least one or more electric loads on the aerial platform **18**. The one or more power sources may include, but are not limited to electrical, solar, mechanical, or chemical energy. For example, in some embodiments, fuel may be used to power one or more components of the aerial platform **18**. Additionally, one or more batteries may be included as one or more power sources for the aerial platform **18**.

[0084] Referring to FIG. **2**, the aerial platform **18** may also include one or more mounting systems **74**. The mounting system **74** may be configured to attach the optical scanner **14** and/or the CDAS system **16** to the aerial platform **18** such that the effects of aerial dynamics and/or external forces for the operation of such systems may be minimized. In some embodiments, the one or more mounting systems **74** may position the optical source **28** and the optical sensor **32** at the separation distance l and angular orientation with respect to the baseline as specified by the pre-determine measurements as provided in detail above. The mounting system **74** may also maintain the separation distance l between the optical source **28** and the optical sensor **32**, and the angular orientation with respect to the baseline within a small error tolerance (e.g., +/−0.01) during flight.

[0085] The mounting system **74** may be formed of materials with combinations of stiffness, weight and strength capable of mounting the optical scanner **14** and/or CDAS system **16** to the aerial platform **18** yet consume a small allotment of carrying capacity of the aerial platform **18**. Generally, the mounting system **74** may position the optical scanner **14** or component of the optical scanner **14** in a rigid manner. In some embodiments, the mounting system **74** may include one or more supports configured to adjust the optical source **28** and/or optical sensor **32**. Additionally, in some embodiments, the mounting system **74** may include one or more ties configured to secure wires between the optical source **28**, the optical sensor **32**, the CDAS system **16**, the onboard data processing and transmission system **20**, and/or the control system **22**, although wireless embodiments are also contemplated.

[0086] FIG. **2** illustrates an exemplary embodiment of the aerial platform **18** wherein the propulsion system **72** is a quadcopter drone. The quadcopter drone may carry the optical source **28** and optical sensor **32** via the mounting system **74**. The CDAS system **16** may be mounted an undercarriage of the aerial platform **18**, for example. Wires may pass through and/or along the mounting system **74** to elements of the aerial scanning system **10** mounted to the aerial platform **18**. In some embodiments, the mounting system **74** may support multiple CDAS systems **16** with each CDAS system **16** positioned in a different direction. In some embodiments, the mounting system **74** may include one or more rotating platforms controlled by a driver (e.g., servo, motor) configured to produce rotational motion. The rotating platform may support the CDAS system **16**, for example, to provide scanning at a large field of view.

[0087] The piloting system **24** may be configured to provide navigation by a user located on the ground. In some embodiments, the piloting system **24** may be configured to provide navigation with the user located at a remote distance from the aerial platform **18**. In some embodiments, the piloting system **24** may be configured to provide autonomous navigation of the aerial platform **18** using some form of artificial intelligence to plan and/or execute scanning and navigation processes.

[0088] Referring to FIG. **5**A, the piloting system **24** may generally include one or more cameras **90** and one or more input-output (I/O) devices **92**. The one or more cameras **90** may be positioned on the aerial platform **18** to obtain data (e.g., video) and transmit the data to the one or more I/O devices **92**. In some embodiments, the one or more cameras **90** may transmit the data via the communication link used for the onboard processing and transmission system **20**. In some embodiments, the one or more cameras **90** may transmit the data via a separate communication link. Exemplary cameras may include, but are not limited to, stereoscopic camera, standard camera, 360 degree camera, and/or the like.

[0089] In some embodiments, the piloting system **24** may provide the user a virtual reality and/or augmented reality experience. For example, the I/O devices **92** may include virtual reality goggles. The virtual reality goggles may immerse the user within a three-dimensional environment representing navigation and/or scanning decisions as if the user was physically located on the aerial platform **18**. Augmented reality goggles may superimpose data over or within the real-time three-dimensional environment. The data may include, but is not limited to, preliminary reconstructed images providing feedback on quality of the scanning process, battery life of the aerial scanning system **10**, status indicators regarding health of systems of the aerial scanning system **10**, navigational data and/or the like. Navigational data may include, but is not limited to, altitude, velocity, direction of flight, wind speed, location of potential obstacles, and/or the like. In some embodiments, the superimposed data may be presented to the user in the form of charts, numbers, gauges, and/or other methods for encoding and displaying such data, and may include, but is not limited to, panels and/or screens overlaying a visual field, organically positioned within the visual field, and/or the like.

[0090] In some embodiments, the I/O device **92** may provide a head tracking system **94**. The head tracking system **94** may provide data on positioning and/or direction of the user's head such that different functionality may occur when the user rotates their head to the left, right, up or down, for example. The head tracking system **94** may communication with the camera **90** and/or the onboard data and transmission system **20** and direct the camera **90** to provide the user with a view corresponding the direction the user's head is positioned. For example, the user may be viewing a first field of view. If the user's head moves to the left, the I/O device **92** may communicate to the onboard processing and transmission system **20** or directly to the camera **90** to alter the viewing direction of the camera **90** and provide a second field of view. The second field of view may be similar to the positioning of the user's head in relation to the camera **90**. In some embodiments, if the user's head moves in a particular direction (e.g., left), the I/O device **92** may provide the user an update on one or more status indicators, and/or the like.

[0091] FIGS. **5**B and **5**C illustrate exemplary piloting system **24** for use in the aerial scanning system **10**. Referring to FIG. **5**B, in some embodiments, the camera **90** in the piloting system **24** may be a stereoscopic camera mounted to

a mechanical device **96** configured to rotate and/or vary direction of the camera **90**. For example, the mechanical device **96** may include, but is not limited to, a gimbaled platform, a rotating platform, and/or the like. In some embodiments, the mechanical device **96** may be configured to position the camera **90** based on direction provided by the I/O device **92**. Referring to FIG. **5**C, in some embodiments, the camera **90** of the piloting system **24** may be a 360 degree camera or its equivalent that may collect and/or transmit visual environment data from one or more sub-cameras **98** positioned to capture the view in the direction desired by the user. In some embodiments, the camera **90** of the piloting system **24** may capture all views from all directions. The control system **22** may select which view of interest is to be delivered based on heading tracking, input via the I/O devices **92**, and/or the like. Such selection by the control system **22** may be automatic (e.g., without human intervention) in some embodiments. The sub-cameras **98** may be positioned in a spherical housing **100**. An exemplary 360 degree camera for use in the piloting system **24** may be the Ozo camera designed for filming virtual reality by Nokia, having a principal place of business in Helsinki, Finland. Other embodiments of the piloting system **24** including variations in sub-cameras **98**, cameras **90** and/or I/O devices **92** are contemplated.

[0092] In some embodiments, the piloting system **24** may include autonomous navigation. For example, a user may provide the control system **22** on the aerial platform **18** with a definition and/or description of the structure **12**. The control system **22** may autonomously determine and/or execute a scanning plan based on the definition and/or description of the structure **12**. The definition and/or description of the structure **12** may include, but is not limited to, simplified model of the structure **12**, geometric description of the real or effective outer surface of the structure **12**, structural characteristics (e.g., solid mass, open grid of beam and/or supports, and/or the like), range of feature sizes of the structure **12**, scanning path, flight path, targeting scanning accuracy, and/or the like. The user may provide the definition or description of the structure **12** in one or more formats such as, for example, spreadsheet file, CAD file, alphanumeric listing, and/or the like.

[0093] The control system **22** may use any known algorithm in the art to direct the aerial platform **18**. Such algorithms may be modified for specific application or capabilities of the aerial platform **18**. In some embodiments, one or more algorithms may be developed to aid in directing the aerial platform **18**. Algorithms may provide a plan consisting of a sequence of one or more actions, both in navigation and in scanning, that the aerial scanning system **10** may execute in order to scan the structure **12**. Additional hardware, firmware, or some combination, may convert actions into control signals needed to execute the plan.

[0094] In some embodiments, the control system **22** may then employ artificial intelligence (AI) resources to compute a plan for navigation around and scanning the structure **12**. In some embodiments, the AI resources (i.e., hardware, firmware) may be solely positioned on the aerial platform **18**. In some embodiments, one or more portions of the AI resources may be positioned at a distance from the aerial platform **18**. In some embodiments, one or more portions of the AI resources may be cloud-based.

[0095] In addition to the definition and/or description of the structure **12**, the AI resources may utilize data and/or pre-programmed knowledge regarding scanning, processing, and other systems present on the aerial scanning system **10** as inputs for planning algorithms. The AI resources may continuously monitor the environment, data from the CDAS system **16**, and scanning quality of the optical scanner **14** to make real-time adjustments to ensure high-quality scanning and survival of the aerial platform **18** during flight.

[0096] Referring to FIGS. **1** and **6**, the control system **22** may be configured to provide data processing, control of the optical scanner **14** and CDAS system **16**, piloting system **24**, transmission of data to the collection station **40** and/or cloud for further processing, and/or the like.

[0097] In some embodiments, the control system **22** may determine the number of illumination patterns displayed per second, the illumination time for each pattern, and the time at which the optical scanner **14** samples and/or stores the output for further processing and/or transmission. The control system **22** may initiate a scanning operation for the optical scanner **14** by activating an image generator within the optical source **28**. For example, for a DMD, the control system **22** may select which mirrors in the array may direct light towards the structure **12**. In another example, for an LCD, the control system **22** may determine which liquid crystal cells may remain opaque and which liquid crystal cells may become transparent allowing for light to reach the structure **12**. In another example, for an array of light emitters, the control system **22** may selectively turn on emitters that contribute to a desired optical pattern **30**.

[0098] In some embodiments, the control system **22** may transmit a gating or timing signal to the optical sensor **32**. Timing signals may trigger one or more events in the aerial scanning system **10** and may include, but are not limited to, a single pulse acting as a triggering mechanism, two or more bits encoding one or more messages, and/or the like. For example, a first timing signal may alert the optical sensor **32** to the release of a first optical pattern **30** and ready data collection circuitry with the optical sensor **32**. The control system **22** may transmit a second pair of timing signals to deactivate the pattern generator within the optical source **28** and terminate sensing and collection by the optical sensor **32**. The timing signals may ensure that the optical sensor **32** only collect light when the optical source **28** illuminates the structure **12** or a distinct portion of the structure **12**, for example. Additionally, the timing signal may be configured such that the optical sensor **32** has sufficient time to collect the optical power needed to eventually provide precise and/or accurate data for reconstruction. In some embodiments, the timing signal may be configured such that data collected for a first optical pattern **30** may be transmitted and/or erased from the optical sensor **32** prior to collection of data from a second optical pattern **30**.

[0099] The control system **22**, in total or in part, may receive data from the CDAS system **16** and determine the existence and/or location of obstacles that impede the flight path of the aerial platform **18**. The control system **22** may implement one of several existing algorithms in the art to process the data. The control system **22** may convert the output of the processing into one or more signals that exert control over the propulsion system **72** and/or navigation system **52** of the aerial platform **18**. In some embodiments, the control system **22** may provide a user with information regarding obstacles and/or corrective action taken or needed, if applicable. The control system **22** may provide one or more control signals in formats for input to the propulsion

system **72** and/or navigation system **52**, with the format dependent on the aerial platform **18** in use. The user may receive signals in the form of, but not limited to, spatial representations, alarms, obstacle location and/or range data, corrections to the navigation path of the aerial platform **18**, and/or the like. Such signals may allow for the user to determine appropriate corrective action needed and/or to correct the scanning process for a new navigational path.

[0100] In some embodiments, the control system **22** may compress data collected from the optical sensor **32**. Data compression may minimize both memory and/or transmission capacity needed to store and/or transmit data. One or more data compression algorithms known within the art may be used to compress the data.

[0101] Additionally, the control system **22** may determine preliminary registration of such data to compensate for movement of the aerial platform **18** between captures by the optical sensor **32**. Generally, in construction of a three-dimensional model of the structure **12**, set of points contained within different captures of the structure **12** illuminated by the optical source **28** may be registered. The registration process may align the acquired data sets with a consistent frame of reference. Such reference may establish a relationship among sets of data and thus aid in fusing measurements into cohesion. For example, to produce a full three-dimensional file (e.g., CAD file) of the structure **12**, the control system **22**, onboard processing and transmission system **20** and/or the collection station **40** may conduct a process known as stitching (e.g., three-dimensional point cloud registration) to transform multiple smaller scans to a large scan of the structure **12**. Each small scan may produce a three dimensional point cloud of the scan. Generally, as much as possible depth image of the structure **12** may be captures from one or more angles covering the surface of interest of the structure **12**. Each sequenced pair of scan may have one or more overlap areas. Point clouds from each scan may be extracted. Three-dimensional registration may be performed on the extracted points. Generally, any algorithm may be used that minimizes the non-matched points such that matched points may be aligned.

[0102] Further, the control system **22** may use detection of movement of the aerial platform **18** to remove and/or reduce effects of such movement on any set of scans. Such removal and/or reduction may reduce processing needed and/or the modelling error produced by software. Detection of movement of the aerial platform **18** may include, but is not limited to, use of one or more accelerometers, gyroscopes, and/or the like.

[0103] In some embodiments, the control system **22** and/or the onboard processing and transmission system **20** may be configured to encapsulate data into a format used for transmission to the collection station **40** or other off-site receiver. For example, transmission may use protocols including, but not limited to, WiFi, 5G, 4G LTE, and/or the like. The control system **22** may deliver formatted and/or encapsulated data via the onboard data and transmission system **20**. The onboard data and transmission system **20** may transmit the data to the collection station **40** or other off-site receiver.

[0104] The control system **22** and/or the collection station **40** may include processing software configure to construct one or more three-dimensional models of the structure **12** and/or express the model in one or more formats for use in modelling and design software. For example, the final file format for the model may include, but is not limited to, PDF, file formats supported by the program SolidWorks developed by Dassault Systemes having a principal place of business in France, and/or the like. It should be noted that algorithms within the processing software may be modified and/or specialized for systems in the aerial scanning system **10**.

[0105] FIG. **6** illustrates an exemplary flow chart **110** for the control system **22**, onboard processing and transmission system **20** and/or collection station **40** to perform to provide one or more three-dimensional models of the structure **12**.

[0106] In some embodiments, prior to scanning, the optical source **28** and/or the optical sensor **32** may be calibrated. Camera-projector calibration process may determine intrinsic parameters of the optical sensor **32**, intrinsic parameters of the optical source, stereo system extrinsic calibration parameters, and/or the like.

[0107] Intrinsic parameters of the optical sensor **32** and optical source **28** may include, but are not limited to, focal length, principal point offset, skew, radial distortion, tangential distortion, and/or the like. Such parameters may vary from the optical sensor **32** to the optical source **28** depending on model of use.

[0108] Stereo system extrinsic calibration parameters may include, but are not limited to, rotation matrix, translation vector, and/or the like. These two matrices may describe how the optical sensor **32** and the optical source **28** centers are located in relation to one another. For example, if each center is in the same location (i.e., theoretical as three-dimensional reconstruction is not viable), an identity rotation matrix may be determined and a zero translation vector.

[0109] Generally, calibration may be via a static method or interactive method. In the static method, parameters may be known during design and/or measured subsequent to fabrication. For example, focal length may be physically measured, distortion may be cancelled with careful designs, and/or the like. Extrinsic parameters may also be measured during the design stage. For example, both the optical sensor **32** and the optical source **28** may be adjusted in parallel. Then, the rotation matrix may be an identity. Each may be fixed in the same Y-axis with 5 CM different at the X-axis. As such, the translation matrix may also be known.

[0110] For calibration using the interactive method, all parameters may be considered unknown. The calibration process may then identify parameters depending on a previously known object. In using the interactive method, a non-square pattern may be used (e.g., a chess-board pattern). The dimensions of the pattern and may be known. Generally, the optical sensor **32** may capture an image of the pattern with the presence of the optical source **28** lighting on it. Images captured by the optical sensor **32** may be analyzed to detect the corners of the pattern. As the patterns dimensions are known, intrinsic parameters of the optical sensor **32** may be identified. To identify the parameters of the optical source **28**, a transformation may be done from the space of the optical sensor **32** to the space of the optical source **28**. This transformation may be done using the pattern. For example, the pattern projected by the optical source **28** may be decoded and matched pairs between the optical sensor **32** and the optical source **28** may be identified. Using a homograph transform, the transformation may move from the space of the optical sensor **32** to the space of the optical source **28**. As such, an artificial image may identify how the optical source **28** sees the pattern. Intrinsic param-

eters of the optical source **28** may be identified similar to the intrinsic parameters of the optical sensor **32**. Once the optical sensor **32** and the optical source **28** are calibrated, translation and rotation between the optical sensor **32** and the optical source **28** may be identified using matched points, and extrinsic parameters of the optical source **28** may then be identified using a simple linear system of equations.

[0111] In some embodiments, a hybrid method using the static calibration and interactive calibration may be used. For example, if focal length is 100% known, then this number may be used in the interactive method to solve for other parameters. Additional calibration methods are further described in the article entitled, *Simple, Accurate, and Robust Projector-Camera Calibration* by Daniel Moreno and Gabriel Taubin, Brown University, School of Engineering, which is hereby incorporated by reference in its entirety.

[0112] In a step **112**, the optical scanner **14** may be directed to scan the structure **12** and obtain data (e.g., images) of the structure **12**. In some embodiments, scanning each part of the structure **12** multiple times may provide potential for increased accuracy and/or precision. A larger structure **12** may need the optical source **28** to illuminate portions of the structure **12** multiple times and/or conduct a set of scans for each portion of the structure **12** to be capable of recoding data on the entire structure **12**. Additionally, the optical source **28** may illuminate portions of the structure **12** multiple times and/or conduct a set of scans for each portion of the structure **12** at same and/or similar angles and different angles. Exemplary optical patterns **30** and measurement techniques may be found in the article by Jason Geng, *Structured-light 3D Surface Imaging: a tutorial*, Advances in Optics and Photonics 3, 128-160 (2011), which is hereby incorporated by reference in its entirety.

[0113] The calibrated system may be able to identify X, Y and Z of any points relative to the frame of the optical sensor **32** which originates in the center of the lens of the optical sensor **32**. This coordinator may be expressed in real world units (e.g., CM). However, these points are expressed relatively to the location of the optical sensor **32**. In some embodiments, a reference frame may be provided. The reference frame may provide guidance on location of the aerial platform **18** relative to the reference frame. For example, using overlap of scans, a first scan may be performed with a reference corner and/or one or more additional reference points visible to the optical scanner **14**. The position of the optical scanner **14** may be determined. A second scan may then be performed with the second scan overlapping at least a portion of the first scan. With such overlap, the first scan and the second scan share at least one point at which position of optical scanner **14** during the second scan may be determined using geometrical computations.

[0114] In a step **114**, the scans may be aligned via one or more registration processes. The one or more registration processes may align data sets, from a single section or among adjacent scanned section, with a consistent frame of reference as described in further detail herein. The registration process may establish relationships among the sets aiding in fusing measurements into a cohesive whole. During the step **114**, movement of the aerial platform **18** (e.g., lateral, longitudinal, angular movement) occurring between instances of data collection by the optical sensor **32** may be accounted for. For example, movement data related to the aerial platform **18** may be collected in addition to raw or pre-processed data from the optical sensor **32**. In some embodiments, registration performed in the collection station **40** may complement any pre-processing or registration determination performed in the control system **22**. The registration process may also consider and/or account for overlap in scans of neighbouring sections of the structure **12** in establishing a common frame of reference. For example, allowing adjacent scan segments to overlap may provide the registration algorithm with additional information improving accuracy and/or precision of the processing software in constructing a cohesive model from individual portions.

[0115] In a step **116**, gaps between data points may be accounted for and filled in. Gaps may arise from the discrete nature of either the optical source **28** or the optical sensor **32** (e.g., pixilated sensors). Such gaps may be generalized, or filled in to smooth out the visual representation. The filling may be based on deep learning and/or AI algorithms, which may incorporate a learned process after several scans of the structure **12**, for example. Such learning processes may aid the algorithm in estimation of shape of each portion of the structure **12** and fill in gaps.

[0116] In a step **118**, outputs of previous steps may be combined to provide a single object such as the three-dimensional model. In some embodiments, several iterations of steps **116** and **118** may be performed to provide the single object. In a step **120**, the single object may be converted into a format suitable for a target application. Such target application may include manufacturing, engineering and design applications.

[0117] The aerial scanning system and methods disclosed and claimed herein are well adapted to carry out the objects and to attain the advantages mentioned herein, as well as those inherent in the invention. While exemplary embodiments of the concepts disclosed herein have been described, it will be understood that numerous changes may be made which will readily suggest themselves to those skilled in the art and which are accomplished within the spirit of the inventive concepts disclosed and claimed herein.

What is claimed is:

1. An aerial scanning system for creating a model of a structure, comprising:

an aerial platform configured to follow a flight path of movement about the structure;

an optical scanner comprising:

at least one optical source configured to project at least one optical pattern on the surface of the structure; and

at least one optical sensor configured to record data related to the at least one optical pattern projected on the surface of the structure;

a piloting system providing the flight path of movement about the structure to the aerial platform; and,

a control system executing processing software reading:

data corresponding to the at least one surface of the structure; and,

data corresponding to movement of the aerial platform about the structure;

wherein the processing software executed by the control system determines a three dimensional model of the structure using data corresponding to the surface of the structure and data corresponding to movement of the aerial platform about the structure.

2. The aerial scanning system of claim **1**, wherein a single optical pattern is projected by the at least one optical source,

and recorded by the optical sensor to determine a frame of information using a single shot algorithm.

3. The aerial scanning system of claim **1**, wherein the at least one optical pattern includes a series of optical patterns.

4. The aerial scanning system of claim **3**, wherein the aerial platform is configured to remain static during projection of the series of optical patterns.

5. The aerial scanning system of claim **1**, wherein the optical source and the optical sensor are rigidly mounted on the aerial platform such that the optical source and optical sensor remain in a static geometric relationship.

6. The aerial scanning system of claim **1**, wherein data obtained from the optical sensor is combined with known distance between the optical source and the optical sensor, angular orientation of the optical source and the optical sensor and content of the optical pattern to determine the model of the structure.

7. The aerial scanning system of claim **1**, wherein the optical scanner includes at least one LiDAR system.

8. The aerial scanning system of claim **7**, wherein the optical scanner includes at least one LiDAR system positioned on the aerial platform for horizontal scanning and at least one LiDAR system positioned on the aerial platform for vertical scanning wherein each LiDAR system captures horizontal resolution.

9. The aerial scanning system of claim **1**, further comprising a collision detection and avoidance system including an environment mapping system configured to obtain data regarding at least one object in an environment surrounding the aerial platform;

wherein the control system executes processing software reading data corresponding to at least one object in the environment around the aerial platform and determines a second flight path for the piloting system to avoid the at least one object.

10. The aerial scanning system of claim **1**, wherein the object in the environment about the aerial platform is the structure and the control system determines proximity of the aerial platform to the structure.

11. The aerial scanning system of claim **1**, wherein the piloting system is autonomous.

12. The aerial scanning system of claim **1**, wherein the piloting system is directed by a user.

13. The aerial scanning system of claim **1**, wherein data corresponding to the at least one surface of the structure includes at least two scans of at least one optical pattern.

14. The aerial scanning system of claim **13**, wherein the scans are aligned via a registration process such that a consistent frame of reference between each scan is established.

15. The aerial scanning system of claim **14**, wherein data corresponding to movement of the aerial platform about the structure is used in determination of the consistent frame of reference between each scan.

16. The aerial scanning system of claim **1**, wherein the piloting system includes a camera and an I/O device, the camera is positioned on the aerial platform and obtains data of surrounding environment about the aerial platform and transmits the data to the I/O device.

17. The aerial scanning system of claim **16**, wherein the I/O device is a virtual reality device providing a three-dimensional environment representation based on the data obtained from the camera of the piloting system.

18. An automated method of constructing a three-dimensional model of a structure, comprising:

receiving data sets related to a series of optical patterns projected onto the structure;

receiving data related to one or more movements of an aerial platform traveling on a flight path;

determining alignment of the data sets, wherein such determination uses data related to one or more movements of the aerial platform on the flight path; and,

combining data sets to provide the three-dimensional model of the structure.

19. The automated method of constructing a three-dimensional model of a structure of claim **18**, further comprising the step of receiving data related to one or more objects in a flight path of an aerial platform; and altering the flight path of the aerial platform to avoid the one or more objects.

20. An autonomous, real-time aerial scanning system, comprising:

an aerial platform having a propulsion system including at least four rotors;

an autonomous piloting system having a pre-defined flight path about a structure and configured to direct the at least four rotors of the aerial platform;

a collision detection and avoidance system configured to identify at least one object within the flight path;

an optical scanner including an optical source and an optical sensor, the optical source configured to provide a series of optical patterns on at least one surface of the structure for detection by the optical sensor;

a control system executing processing software reading:

data corresponding to the at least one surface of the structure obtained by the optical sensor;

data corresponding to the at least one object within the flight path; and,

data corresponding to movement of the aerial platform about the structure;

wherein the processing software executed by the control system determines a second flight path based on the at least one object; and

wherein the processing software transmit data corresponding to the surface of the structure and data corresponding to movement of the aerial platform about the structure to a collection station.

* * * * *