MOBILE VISUAL-INSPECTION SYSTEM

FIELD

This disclosure relates generally to visual-inspection systems, and more particularly to ground-based mobile visual-inspection systems for inspecting large structures, such as aircraft.

BACKGROUND

Aircraft and other mobile vehicles sometimes require inspection for wear. One type of inspection is visual-inspection. For large vehicles, visual-inspection can be difficult to accomplish. For many hard to reach areas, drones or other unmanned aerial vehicles are used to fly cameras close to the aircraft. However, drones have vibrating parts and may be adversely affected by weather conditions, such as wind or precipitation. To prevent the drones from impacting the aircraft, the drones are flown a safe distance from the aircraft, which results in less than ideal photographs and video of the aircraft.

SUMMARY

The subject matter of the present application has been developed in response to the present state of the art, and in particular, in response to the problems and disadvantages associated with conventional fixtures that have not yet been fully solved by currently available techniques. Accordingly, the subject matter of the present application has been developed to provide embodiments of a system, an apparatus, and a method that overcome at least some of the above-discussed shortcomings of prior art techniques. For example, according to one implementation, ground-based mobile visual-inspection system is disclosed, which facilitates the capture of steady and precisely-located photos and videos.

An aspect of the present disclosure provides a ground-based visual-inspection system for inspecting a structure. The ground-based visual-inspection system includes a ground-based visual-inspection apparatus that includes a mobile base that translationally moves relative to a reference position to define a translational displacement of the mobile base;

an actuatable arm coupled to the mobile base, the actuatable arm locatable in a three-dimensional space; and an end effector coupled to the actuatable arm. The end effector includes a set of at least three laser rangefinders; and a camera, wherein the camera is oriented relative to the structure in response to input from the set of at least three rangefinders, wherein a perpendicular distance between the structure and the camera is measured by the rangefinders, wherein a rotational orientation of the camera is determined relative to the reference position of the mobile base, and wherein the camera is configured to capture a set of visual images of a surface of the structure. The ground-based visual-inspection system also includes a control system that embeds the perpendicular distance to the surface of the structure within the set of visual images captured by the camera. The control system includes an alignment system comprising the set of at least three laser rangefinders spaced around a perimeter of the camera; and a feedback system configured to utilize the set of at least three laser rangefinders to measure the perpendicular distance and the rotational orientation of the camera relative to each target area located on the surface of the structure without using optical targets, wherein the camera and the set of at least three laser rangefinders are non-movably fixed, relative to each other, and the end effector rotates the set of at least three laser rangefinders relative to the structure and moves the camera toward or away from the structure until the set of at least three laser rangefinders measures the same perpendicular distance to the surface of the structure; utilize the feedback system to, while translationally moving the camera along the surface of the structure: automatically adjust the perpendicular distance and the rotational orientation of the camera to maintain the set of at least three laser rangefinders at the same perpendicular distance from the surface of the structure and to maintain the rotational orientation of the camera perpendicular to the surface of the structure being captured by the set of visual images as the ground-based visual-inspection apparatus translationally moves the end effector relative to the reference position; and continuously adjust the alignment of the camera to maintain the perpendicular alignment of the camera relative to each target area located on the surface of the structure as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during inspection of the structure,

determine location information of the camera in three-dimensions relative to a reference location, and associate the three-dimensional location information of the camera with location information for each respective target area located on the surface of the structure captured by the set of visual images as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during the inspection of the structure.

Another aspect of the present disclosure provides a method comprising aligning a ground-based visual-inspection apparatus to a structure, the ground-based visual-inspection apparatus comprising a mobile base that translates relative to a reference position, an actuatable arm coupled to the mobile base, and an end effector coupled to the actuatable arm, wherein the end effector comprises a camera oriented relative to a structure wherein a perpendicular distance between the camera and the structure is measured by an alignment system comprising a set of at least three laser rangefinders spaced around a perimeter of the camera; measuring, via the set of at least three laser range finders, a perpendicular distance between the camera and the structure and an orientation of the camera relative to each target area located on a surface of the structure without using optical targets; automatically adjusting the set of at least three laser rangefinders so that they each measure the same perpendicular distance from the surface of the structure to the camera and adjusting an orientation of the camera that is perpendicular to the surface of the structure being captured by the set of visual images as the ground-based visual-inspection apparatus changes position; continuously adjusting the alignment of the camera to maintain the perpendicular alignment of the camera relative to each target area located on the surface of the structure as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during inspection of the structure; capturing a set of visual images of each target area on the surface of the structure with the camera; wherein the perpendicular distance between the camera and the surface of the structure is embedded in the set of visual images; determining location information of the camera in three-dimensions relative to a reference location by acquiring a base location, arm location, and end effector location relative to a reference location; and associating the

three-dimensional location information of the camera with location information for each respective target area located on the surface of the structure captured by the set of visual images as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during the inspection of the structure.

Disclosed herein is a ground-based visual-inspection system including a ground-based visual-inspection apparatus and a control system. The ground-based visual-inspection apparatus includes a mobile base, an actuatable arm coupled to the mobile base, and an

CLAIMS

1. A ground-based visual-inspection system for inspecting a structure, the ground-based visual-inspection system comprising:

a ground-based visual-inspection apparatus comprising:

a mobile base;

an actuatable arm coupled to the mobile base, the actuatable arm locatable in a three-dimensional space; and

an end effector coupled to the actuatable arm, wherein the end effector comprises a camera configured to capture images of the structure; and

a control system, wherein the control system is configured to determine location information of the camera relative to a reference location and associate the location information with the images.

2. The ground-based visual-inspection system according to claim 1, wherein the control system is further configured to determine the location information by determining a location of the camera relative to the reference location by:

acquiring a base location by computing a transformation matrix of the mobile base relative to the reference location;

acquiring an arm location by computing a transformation matrix of the actuatable arm relative to the reference location; and

performing matrix multiplication of the transformation matrix of the mobile base and the transformation matrix of the actuatable arm to compute a transformation matrix of the end effector relative to the reference location.

3. The ground-based visual-inspection system according to any of claims 1-2, wherein the control system further comprises an alignment system comprising a plurality of laser rangefinders coupled to the end effector.

~~4. The ground-based visual-inspection system according to claim 3, wherein the alignment system is configured to determine an orientation of the camera relative to the structure based on data of the plurality of laser rangefinders.~~

~~5. The ground-based visual-inspection system according to claim 4, wherein the control system is further configured to embed orientation information of the camera in the images.~~

~~6. The ground-based visual-inspection system according to claim 3, wherein the alignment system is configured to determine a distance of the camera relative to the aircraft based on data captured by the plurality of laser rangefinders.~~

~~7. The ground-based visual-inspection system according to claim 6, wherein the control system is further configured to embed distance information in the images.~~

~~8. The ground-based visual-inspection system according to any of claims 1-7, wherein the control system is configured to embed the location information into the image.~~

~~9. The ground-based visual-inspection system according to claim 8, wherein the location information is based on data from sensors on the ground-based visual-inspection apparatus or the structure.~~

~~10. The ground-based visual-inspection system according to any of claims 1-9, wherein the location information is based on a reference location on the structure.~~

~~11. The ground-based visual-inspection system according to any of claims 1-10, wherein the mobile base comprises a cart maneuverable by manual power.~~

~~12. The ground-based visual-inspection system to any of claims 1-11, further comprising an alignment system comprising a plurality of laser rangefinders coupled to the end effector, wherein:~~

~~the alignment system is configured to determine an orientation and a distance of the camera relative to the structure based on data of the plurality of laser rangefinders;~~

~~the control system is further configured to embed orientation information and distance information with the images; and~~

~~the control system is further configured to embed the location information into the image.~~

~~13. The ground-based visual-inspection system according to claim 12, wherein the location information comprises a translational displacement from a reference position and rotational displacement from a reference orientation of the mobile base relative to the reference location.~~

~~14. The ground-based visual-inspection system according to any of claims 1-13, wherein the actuatable arm comprises an indexing rail.~~

~~15. A ground-based visual-inspection apparatus comprising:~~

~~a mobile base;~~

~~an actuatable arm coupled to the mobile base, the actuatable arm locatable in a three dimensional space;~~

~~an end effector coupled to the actuatable arm, wherein the end effector comprises a camera configured to capture images of a structure; and~~

~~a control system, wherein the control system is configured to determine location information of the camera relative to a reference location.~~

~~16. The apparatus according to claim 15, further comprising a plurality of laser rangefinders coupled to the end effector.~~

~~17. A method comprising:~~

~~aligning a ground-based visual-inspection apparatus to a structure, the ground-based visual-inspection apparatus comprising a mobile base, an actuatable arm coupled to the mobile base, and an end effector coupled to the actuatable arm, wherein the end effector comprises a camera;~~

~~capturing an image of the structure with the camera;~~

~~determining location information of the camera relative to a reference location by acquiring a base location, arm location, and end effector location relative to a reference location; and~~

~~associating the location information with the image.~~

~~18. The method according to claim 17, further comprising receiving data from sensors and automatically adjusting the orientation or distance of the camera relative to the structure based on the received data.~~

~~19. The method according to any of claims 17-18, further comprising:~~

~~acquiring the base location by computing a transformation matrix of the mobile base relative to the reference location;~~

~~acquiring the arm location by computing a transformation matrix of the actuatable arm relative to the reference location; and~~

~~performing matrix multiplication of the transformation matrix of the mobile base and the transformation matrix of the actuatable arm to compute a transformation matrix of the end effector relative to the reference location.~~

~~20. The method according to any of claims 17-19, further comprising:~~

~~determining distance information and orientation information of the camera relative to the structure; and~~

~~associating the distance information and the orientation information with the image.~~

1. A ground-based visual-inspection system for inspecting a structure, the ground-based visual-inspection system comprising:

a ground-based visual-inspection apparatus comprising:

a mobile base that translationally moves relative to a reference position to define a translational displacement of the mobile base;

an actuatable arm coupled to the mobile base, the actuatable arm locatable in a three-dimensional space; and

an end effector coupled to the actuatable arm, the end effector comprising:

a set of at least three laser rangefinders; and

a camera, wherein the camera is oriented relative to the structure in response to input from the set of at least three rangefinders, wherein a perpendicular distance between the structure and the camera is measured by the rangefinders, wherein a rotational orientation of the camera is determined relative to the reference position of the mobile base, and wherein the camera is configured to capture a set of visual images of a surface of the structure; and

a control system that embeds the perpendicular distance to the surface of the structure within the set of visual images captured by the camera, the control system comprising:

an alignment system comprising the set of at least three laser rangefinders spaced around a perimeter of the camera; and

a feedback system configured to:

utilize the set of at least three laser rangefinders to measure the perpendicular distance and the rotational orientation of the camera relative to each target area located

on the surface of the structure without using optical targets, wherein the camera and the set of at least three laser rangefinders are non-movably fixed, relative to each other, and the end effector rotates the set of at least three laser rangefinders relative to the structure and moves the camera toward or away from the structure until the set of at least three laser rangefinders measures the same perpendicular distance to the surface of the structure;

utilize the feedback system to, while translationally moving the camera along the surface of the structure:

automatically adjust the perpendicular distance and the rotational orientation of the camera to maintain the set of at least three laser rangefinders at the same perpendicular distance from the surface of the structure and to maintain the rotational orientation of the camera perpendicular to the surface of the structure being captured by the set of visual images as the ground-based visual-inspection apparatus translationally moves the end effector relative to the reference position; and

continuously adjust the alignment of the camera to maintain the perpendicular alignment of the camera relative to each target area located on the surface of the structure as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during inspection of the structure,

determine location information of the camera in three-dimensions relative to a reference location, and

associate the three-dimensional location information of the camera with location information for each respective target area located on the surface of the structure captured by the set of visual images as the mobile base moves along the

ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during the inspection of the structure.

2. The ground-based visual-inspection system according to claim 1, wherein the control system is further configured to determine the location information by determining a location of the camera relative to the reference location by:

acquiring a base location by computing a transformation matrix of the mobile base relative to the reference location;

acquiring an arm location by computing a transformation matrix of the actuatable arm relative to the reference location; and

performing matrix multiplication of the transformation matrix of the mobile base and the transformation matrix of the actuatable arm to compute a transformation matrix of the end effector relative to the reference location.

3. The ground-based visual-inspection system according to claim 1, wherein the control system is further configured to embed orientation information of the camera in the set of visual images.

4. The ground-based visual-inspection system according to claim 1, wherein the control system is configured to embed the location information into the set of visual images.

5. The ground-based visual-inspection system according to claim 4, wherein the location information is based on data from sensors on the ground-based visual-inspection apparatus or the structure.

6. The ground-based visual-inspection system according to claim 1, wherein the location information is based on the reference location on the structure.

7. The ground-based visual-inspection system according to claim 1, wherein the mobile base comprises a cart maneuverable by manual power.

8. The ground-based visual-inspection system according to claim 1, wherein:

the control system is further configured to embed orientation information within the set of visual images; and

the control system is further configured to embed the location information into the set of visual images.

9. The ground-based visual-inspection system according to claim 8, wherein the location information comprises the translational displacement from the reference position and rotational displacement from a reference orientation of the mobile base relative to the reference location.

10. The ground-based visual-inspection system according to claim 1, wherein the actuatable arm comprises an indexing rail.

11. A method comprising:

aligning a ground-based visual-inspection apparatus to a structure, the ground-based visual-inspection apparatus comprising a mobile base that translates relative to a reference position, an actuatable arm coupled to the mobile base, and an end effector coupled to the actuatable arm, wherein the end effector comprises a camera oriented relative to a structure

wherein a perpendicular distance between the camera and the structure is measured by an alignment system comprising a set of at least three laser rangefinders spaced around a perimeter of the camera;

measuring, via the set of at least three laser range finders, a perpendicular distance between the camera and the structure and an orientation of the camera relative to each target area located on a surface of the structure without using optical targets;

automatically adjusting the set of at least three laser rangefinders so that they each measure the same perpendicular distance from the surface of the structure to the camera and adjusting an orientation of the camera that is perpendicular to the surface of the structure being captured by the set of visual images as the ground-based visual-inspection apparatus changes position;

continuously adjusting the alignment of the camera to maintain the perpendicular alignment of the camera relative to each target area located on the surface of the structure as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during inspection of the structure;

capturing a set of visual images of each target area on the surface of the structure with the camera; wherein the perpendicular distance between the camera and the surface of the structure is embedded in the set of visual images;

determining location information of the camera in three-dimensions relative to a reference location by acquiring a base location, arm location, and end effector location relative to a reference location; and

associating the three-dimensional location information of the camera with location information for each respective target area located on the surface of the structure captured by the set of visual images as the mobile base moves along the ground beside the structure and the actuatable arm moves in three-dimensions relative to the surface of the structure during

the inspection of the structure.

12. The method according to claim 11, further comprising receiving data from sensors and automatically adjusting the orientation or distance of the camera relative to the structure based on the received data.

13. The method according to claim 11, further comprising:

acquiring the base location by computing a transformation matrix of the mobile base relative to the reference location;

acquiring the arm location by computing a transformation matrix of the actuatable arm relative to the reference location; and

performing matrix multiplication of the transformation matrix of the mobile base and the transformation matrix of the actuatable arm to compute a transformation matrix of the end effector relative to the reference location.

14. The method according to claim 11, further comprising:

determining distance information and orientation information of the camera relative to the structure; and

associating the distance information and the orientation information with the set of visual images.

15. The ground-based visual-inspection system according to claim 1, wherein two laser rangefinders in the set of at least three laser rangefinders are located on opposite sides of the camera.

16. The ground-based visual-inspection system according to claim 1, wherein the control system is further configured to embed orientation information within the set of visual images.

17. The ground-based visual-inspection system according to claim 1, wherein the control system is further configured to embed the location information within the set of visual images.

18. The ground-based visual-inspection system according to claim 1, wherein two laser rangefinders in the set of at least three laser rangefinders are located on a same side of the camera and one laser rangefinder in the set of at least three laser rangefinders is located on a side of the camera opposite that of the two laser rangefinders in the set of at least three laser rangefinders.

19. The ground-based visual-inspection system according to claim 1, wherein the surface of the structure is curved and translationally moving the camera along the surface comprises moving the camera along a curved path that complements a curvature of the surface of the structure.

20. The ground-based visual-inspection system according to claim 1, wherein the camera is rotatable relative to the actuatable arm.