Another category of examples of the concept are configurations where UAV contains two or more laser range meters that enables: direct measurement of distance to the target, reference scale, as well as one or more orientation angle of the UAV relative to the target. If three non-collinearly mounted laser range meters are used (not shown here), more than one orientation angle can be measured (for example yaw and pitch). As used herein, the term “laser range meter” (also known as “laser rangefinder”) means a device that emits a laser beam and detects returned laser light.

A third category of examples includes a gimbaled laser range meter is used to acquire distance and aim direction information from the moving platform (e.g., UAV) to objects in the environment. This concept leverages some aspects of the vector-based measurement algorithms disclosed in U.S. Patent No. 7,859,655 (the disclosure of which is incorporated by reference herein in its entirety), along with the addition of sensors, such as an inertial measurement unit, to determine the relative motion of the platform. This platform motion data along with the aim direction and distance data from the gimbaled laser range meter can be used to acquire measurements of objects in the environment.

Although various examples of systems and methods for acquiring scale and point-to-point distance information for objects undergoing non-destructive inspection are described in some detail later herein, one or more of those examples may be characterized by one or more of the following aspects.

One aspect of the subject matter disclosed in detail below is a method for operating an unmanned aerial vehicle, comprising: (a) controlling an unmanned aerial vehicle to fly toward a structure; (b) using first and second laser range meters on-board the unmanned aerial vehicle to repeatedly measure first and second distances respectively separating the first and second laser range meters from respective first and second spots projected on a surface of the structure by the first and second laser range meters while

the unmanned aerial vehicle is flying, wherein respective axes of the first and second laser range meters are mutually parallel and separated by a distance d; (c) calculating a separation distance separating the unmanned aerial vehicle from the structure based at least on the first and second distances; (d) determining whether the separation distance equals a goal offset; (e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset; (f) using a camera on-board the unmanned aerial vehicle to capture an image of the structure with first and second laser spots while the unmanned aerial vehicle is hovering at the first location; (g) calculating a scale factor based on a number of pixels separating two centroids corresponding to the first and second laser spots in the first image and the distance d; (h) ceasing to project the first and second laser spots on the surface of the structure; (i) using the camera to capture a second image of the surface of the structure while the unmanned aerial vehicle is hovering at the first location and the first and second laser spots are absent from the surface; (j) displaying the second image on the display screen; and (k) displaying a scale indicator overlaid on the second image displayed on the display screen, a value or a length of the scale indicator representing the scale factor.

Another aspect is a method for operating an unmanned aerial vehicle, comprising (a) controlling the unmanned aerial vehicle to fly toward a structure; (b) using first and second laser range meters on-board the unmanned aerial vehicle to repeatedly measure first and second distances respectively separating the first and second laser range meters from respective first and second spots on a surface of the structure while the unmanned aerial vehicle is flying; (c) calculating a separation distance separating the unmanned aerial vehicle from the structure based at least on the first and second distances; (d) determining whether the separation distance equals a goal offset; (e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset; (f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first location; (g) displaying the first image on a display screen;

(h) computing an orientation angle of a focal axis of the camera relative to a line connecting the first and second spots on the surface of the structure based on the first and second distances; (i) calculating a scale factor for the first image when displayed on the display screen based at least in part on the separation distance and the orientation angle; and (j) displaying a scale indicator overlaid on the first image, a value or a length of the scale indicator representing the scale factor.

Another aspect is a method for operating an unmanned aerial vehicle, comprising (a) controlling the unmanned aerial vehicle to fly toward a structure; (b) using first, second, and third laser range meters on-board the unmanned aerial vehicle to repeatedly measure first, second, and third distances respectively separating the first, second, and third laser range meters from respective first, second, and third spots on a surface of the structure while the unmanned aerial vehicle is flying; (c) calculating a separation distance separating the unmanned aerial vehicle from the structure based on the first, second, and third distances; (d) determining whether the separation distance equals a goal offset; (e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset; (f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first location; (g) displaying the first image on a display screen; (h) computing first and second orientation angles of the focal axis of the camera relative to a plane defined by the first, second and third spots on the surface of the structure based on the first, second and third distances; (i) calculating a scale factor for the first image when displayed on the display screen based on the separation distance and the first and second orientation angles; and (j) displaying a scale indicator overlaid on the first image, a value or a length of the scale indicator representing the scale factor.

Another aspect is a method for operating an unmanned aerial vehicle, comprising (a) controlling the unmanned aerial vehicle to fly toward a structure; (b) using first, second, and third laser range meters on-board the unmanned aerial vehicle to repeatedly measure first, second, and third distances respectively separating the first, second, and third laser range meters from respective first,

second, and third spots on a surface of the structure while the unmanned aerial vehicle is flying; (c) calculating a separation distance separating the unmanned aerial vehicle from the structure based on the first, second, and third distances; (d) determining whether the separation distance equals a goal offset; (e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the first separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset; (f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first location; (g) displaying the first image on a display screen; (h) computing an orientation angle of a focal axis of the camera relative to the surface of the structure based on the first, second and third distances; (i) detecting a deviation of the orientation angle from a desired orientation angle while the unmanned aerial vehicle is hovering at the first location; and (j) controlling the unmanned aerial vehicle to change its orientation so that the orientation angle equals the desired orientation angle, wherein control of the orientation of the unmanned aerial vehicle is provided by a motion controller on-board the unmanned aerial vehicle.

Another aspect of the subject matter disclosed in detail below is a method for operating an unmanned aerial vehicle, comprising: (a) controlling an unmanned aerial vehicle to hover at a location separated from a structure to be inspected; (b) directing first and second laser pointers pivotably mounted on-board the unmanned aerial vehicle in parallel toward a surface of the structure, the respective pivot axes of the first and second laser pointers being separated by a fixed distance; (c) using the mutually parallel first and second laser pointers to transmit mutually parallel laser beams onto first and second spots respectively while the unmanned aerial vehicle is hovering at the location; (d) using a camera on-board the unmanned aerial vehicle at a first time to capture a first image of a portion of the surface of the structure that includes the first and second spots; (e) pivoting the first and second laser pointers by a predefined angle while the

CLAIMS

1. A method for operating an unmanned aerial vehicle, comprising:

(a) controlling the unmanned aerial vehicle to fly toward a structure;

(b) using first and second laser range meters on-board the unmanned aerial vehicle to repeatedly measure first and second distances respectively separating the first and second laser range meters from respective first and second spots projected on a surface of the structure by the first and second laser range meters while the unmanned aerial vehicle is flying, wherein respective axes of the first and second laser range meters are mutually parallel and separated by a distance d;

(c) calculating a separation distance separating the unmanned aerial vehicle from the structure based at least on the first and second distances;

(d) determining whether the separation distance equals a goal offset;

(e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset;

(f) using a camera on-board the unmanned aerial vehicle to capture a first image of the surface with first and second laser spots while the unmanned aerial vehicle is hovering at the first location;

(g) calculating a scale factor based on a number of pixels separating two centroids corresponding to the first and second laser spots in the first image and the distance d;

(h) ceasing to project the first and second laser spots on the surface of the structure;

(i) using the camera to capture a second image of the surface of the structure while the unmanned aerial vehicle is hovering at the first location and the first and second laser spots are absent from the surface;

(j) displaying the second image on a display screen;

(k) displaying a scale indicator overlaid on the second image displayed on the display screen, a value or a length of the scale indicator representing the scale factor.

2. The method as recited in claim 1, wherein the first and second distances are equal to the goal offset.

3. The method as recited in claim 1, wherein the display screen is not on-board the unmanned aerial vehicle, further comprising:

transmitting a message containing image data representing the first image from the unmanned aerial vehicle;

receiving the message at a ground station; and

extracting the image data representing the first image from the message,

wherein displaying the first image on the display screen comprises controlling states of pixels of the display screen in accordance with the image data.

4. The method as recited in claim 1, further comprising:

controlling the unmanned aerial vehicle to translate to a second location while maintaining the separation distance;

using the camera to capture a third image of the surface of the structure while the unmanned aerial vehicle is hovering at the second location; and

displaying the third image on the display screen.

5. The method as recited in claim 4, wherein the second and third images respectively comprise first and second sets of image data representing partially overlapping or contiguous areas on the surface of the structure.

6. A method for operating an unmanned aerial vehicle, comprising:

(a) controlling the unmanned aerial vehicle to fly toward a structure;

(b) using first and second laser range meters on-board the unmanned aerial vehicle to repeatedly measure first and second distances respectively separating the first and second laser range meters from respective first and second spots on a surface of the structure while the unmanned aerial vehicle is flying;

(c) calculating a separation distance separating the unmanned aerial vehicle from the structure based at least on the first and second distances;

(d) determining whether the separation distance equals a goal offset;

(e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset;

(f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first

location;

(g) displaying the first image on a display screen;

(h) computing an orientation angle of a focal axis of the camera relative to a line connecting the first and second spots on the surface of the structure based on the first and second distances;

(i) calculating a scale factor for the first image when displayed on the display screen based at least in part on the separation distance and the orientation angle; and

(j) displaying a scale indicator overlaid on the first image, a value or a length of the scale indicator representing the scale factor.

7. The method as recited in claim 1, further comprising:

using a third laser range meter on-board the unmanned aerial vehicle to repeatedly measure a third distance separating the third laser range meter from a third spot on the surface of the structure while the unmanned aerial vehicle is flying,

wherein the separation distance is calculated based on the first, second and third distances.

8. A method for operating an unmanned aerial vehicle, comprising:

(a) controlling the unmanned aerial vehicle to fly toward a structure;

(b) using first, second, and third laser range meters on-board the unmanned aerial vehicle to repeatedly measure first, second, and third distances respectively separating the first, second, and third laser range meters from respective first, second, and third spots on a surface of the structure while the unmanned aerial vehicle is flying;

(c) calculating a separation distance separating the unmanned aerial vehicle from the structure based on the first, second, and third distances;

(d) determining whether the separation distance equals a goal offset;

(e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset;

(f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first location; and

(g) displaying the first image on a display screen;

(h) computing first and second orientation angles of the focal axis of the camera

relative to a plane defined by the first, second and third spots on the surface of the structure based on the first, second and third distances;

(i) calculating a scale factor for the first image when displayed on the display screen based on the separation distance and the first and second orientation angles; and

(j) displaying a scale indicator overlaid on the first image, a value or a length of the scale indicator representing the scale factor.

9. The method as recited in claim 1, further comprising:

controlling the unmanned aerial vehicle to fly to a second location;

detecting a deviation of the separation distance from the goal offset after the unmanned aerial vehicle has moved from the first location to the second location; and

controlling the unmanned aerial vehicle to fly to a third location at which the separation distance equals the goal offset, thereby reducing the deviation to zero,

wherein control of the flight of the unmanned aerial vehicle toward the third location is provided by a motion controller on-board the unmanned aerial vehicle.

10. A method for operating an unmanned aerial vehicle, comprising:

(a) controlling the unmanned aerial vehicle to fly toward a structure;

(b) using first, second, and third laser range meters on-board the unmanned aerial vehicle to repeatedly measure first, second, and third distances respectively separating the first, second, and third laser range meters from respective first, second, and third spots on a surface of the structure while the unmanned aerial vehicle is flying;

(c) calculating a separation distance separating the unmanned aerial vehicle from the structure based on the first, second, and third distances;

(d) determining whether the separation distance equals a goal offset;

(e) controlling the unmanned aerial vehicle to hover at a first location separated from the structure by the first separation distance in response to a determination in step (d) that the separation distance is equal to the goal offset;

(f) using a camera on-board the unmanned aerial vehicle to capture a first image of the structure while the unmanned aerial vehicle is hovering at the first location; and

(g) displaying the first image on a display screen;

(h) computing an orientation angle of a focal axis of the camera relative to the

surface of the structure based on the first, second and third distances;

(i) detecting a deviation of the orientation angle from a desired orientation angle while the unmanned aerial vehicle is hovering at the first location; and

(j) controlling the unmanned aerial vehicle to change its orientation so that the orientation angle equals the desired orientation angle,

wherein control of the orientation of the unmanned aerial vehicle is provided by a motion controller on-board the unmanned aerial vehicle.

11. The method as recited in claim 6, further comprising:

controlling the unmanned aerial vehicle to translate to a second location while maintaining the separation distance;

using the camera to capture a second image of the surface of the structure while the unmanned aerial vehicle is hovering at the second location; and

displaying the second image on the display screen.

12. The method as recited in claim 11, wherein the first and second images respectively comprise first and second sets of image data representing partially overlapping or contiguous areas on the surface of the structure.

13. The method as recited in claim 6, further comprising:

using a third laser range meter on-board the unmanned aerial vehicle to repeatedly measure a third distance separating the third laser range meter from a third spot on a surface of the structure while the unmanned aerial vehicle is flying,

wherein the separation distance is calculated based on the first, second and third distances.

14. The method as recited in claim 6, further comprising:

controlling the unmanned aerial vehicle to fly to a second location;

detecting a deviation of the separation distance from the goal offset after the unmanned aerial vehicle has moved from the first location to the second location; and

controlling the unmanned aerial vehicle to fly to a third location at which the separation distance equals the goal offset, thereby reducing the deviation to zero,

wherein control of the flight of the unmanned aerial vehicle toward the third location is provided by a motion controller on-board the unmanned aerial vehicle.

15. The method as recited in claim 8, further comprising:

controlling the unmanned aerial vehicle to translate to a second location while maintaining the separation distance;

using the camera to capture a second image of the surface of the structure while the unmanned aerial vehicle is hovering at the second location; and

displaying the second image on the display screen.

16. The method as recited in claim 15, wherein the first and second images respectively comprise first and second sets of image data representing partially overlapping or contiguous areas on the surface of the structure.

17. The method as recited in claim 8, further comprising:

controlling the unmanned aerial vehicle to fly to a second location;

detecting a deviation of the separation distance from the goal offset after the unmanned aerial vehicle has moved from the first location to the second location; and

controlling the unmanned aerial vehicle to fly to a third location at which the separation distance equals the goal offset, thereby reducing the deviation to zero,

wherein control of the flight of the unmanned aerial vehicle toward the third location is provided by a motion controller on-board the unmanned aerial vehicle.

18. The method as recited in claim 10, further comprising:

controlling the unmanned aerial vehicle to translate to a second location while maintaining the separation distance;

using the camera to capture a second image of the surface of the structure while the unmanned aerial vehicle is hovering at the second location; and

displaying the second image on the display screen.

19. The method as recited in claim 18, wherein the first and second images respectively comprise first and second sets of image data representing partially overlapping or contiguous areas on the surface of the structure.

20. The method as recited in claim 10, further comprising:

controlling the unmanned aerial vehicle to fly to a second location;

detecting a deviation of the separation distance from the goal offset after the unmanned aerial vehicle has moved from the first location to the second location; and

controlling the unmanned aerial vehicle to fly to a third location at which the separation distance equals the goal offset, thereby reducing the deviation to zero,

wherein control of the flight of the unmanned aerial vehicle toward the third location is provided by a motion controller on-board the unmanned aerial vehicle.